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THE STRUCTURAL ENGINEER

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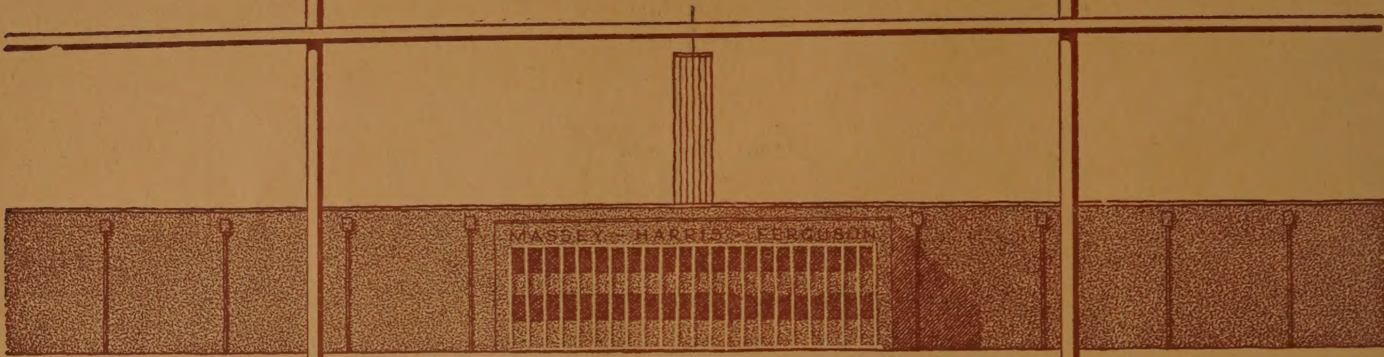
Mathematics and the Structural Engineer
by Dr. E. H. Bateman (Member)

The Use of Semi-graphical Methods in the Stress Deformation Analysis of Shell Forms
by A. S. Tooth, Dr. R. M. Kenedi and J. D. W. Hossack

The North Western Gas Board's New Coal Carbonising Plant at Garston
Discussion on the Paper by H. G. Cousins (Member)

FOUR SHILLINGS AND SIXPENCE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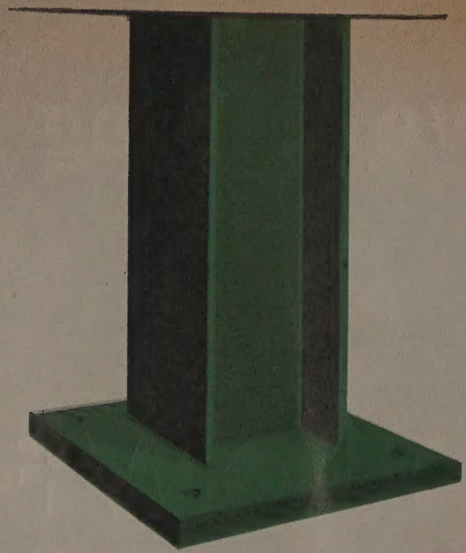

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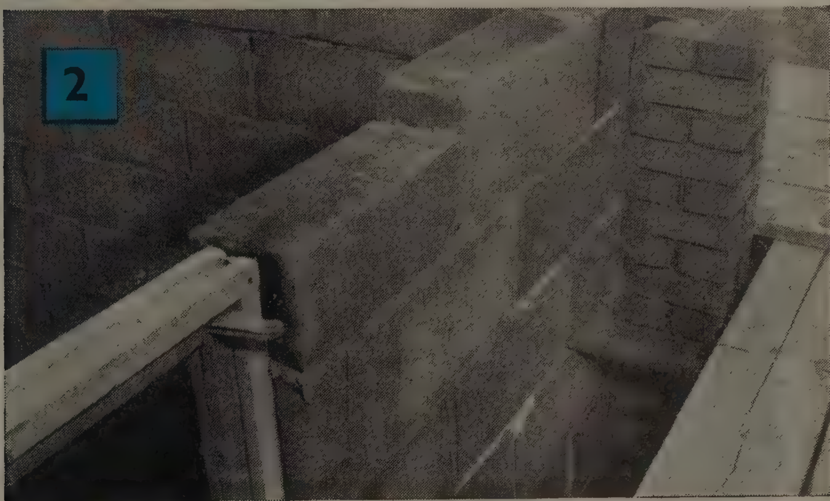
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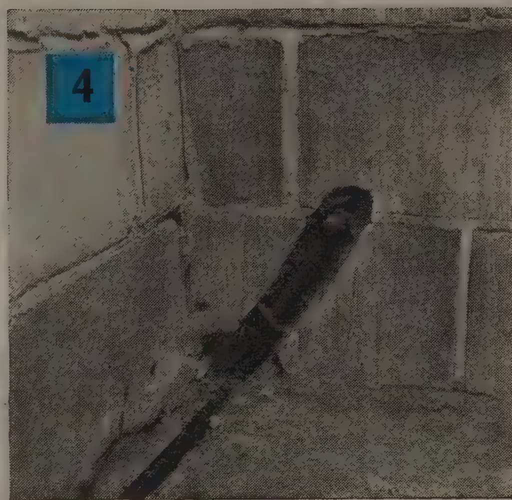
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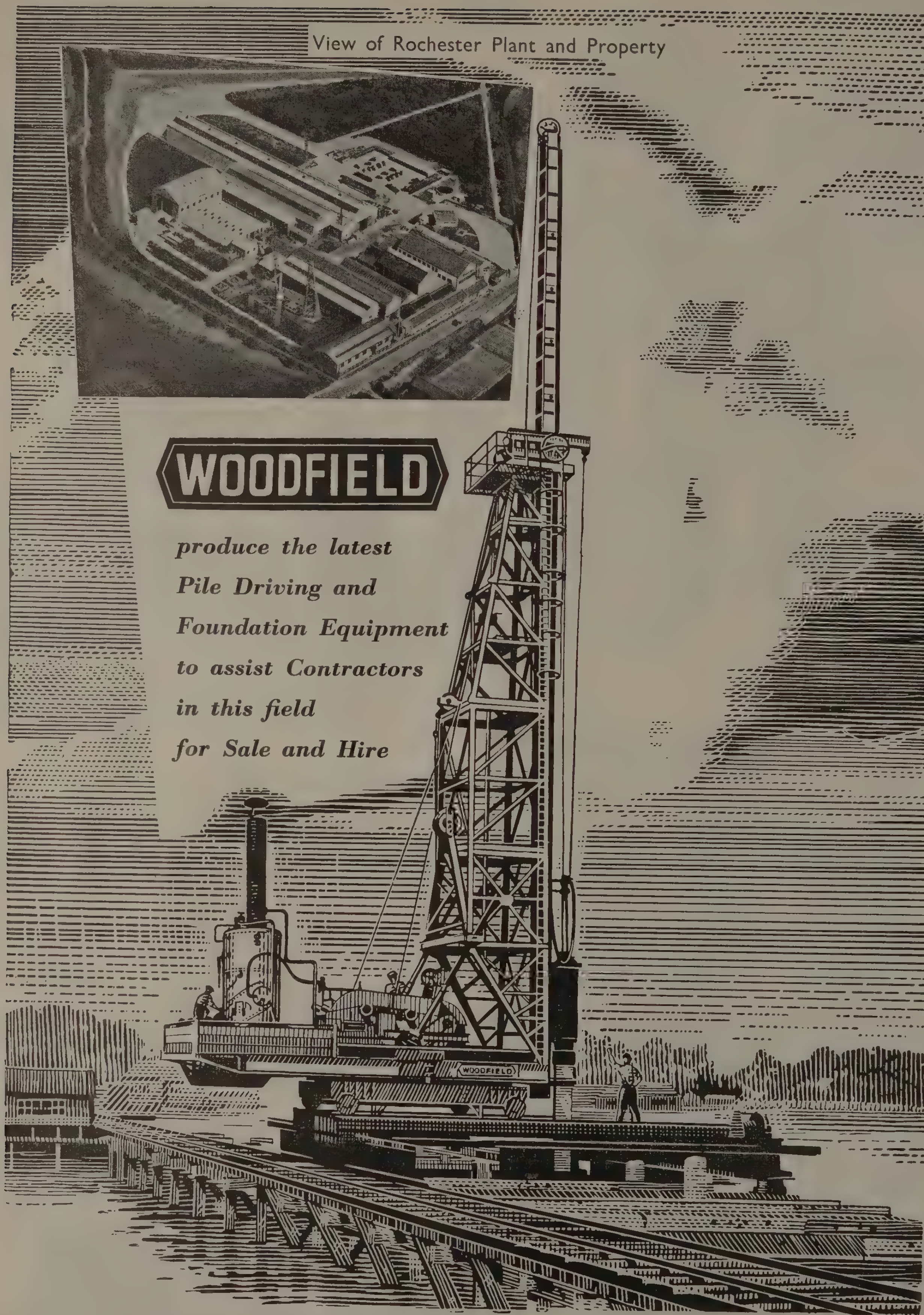
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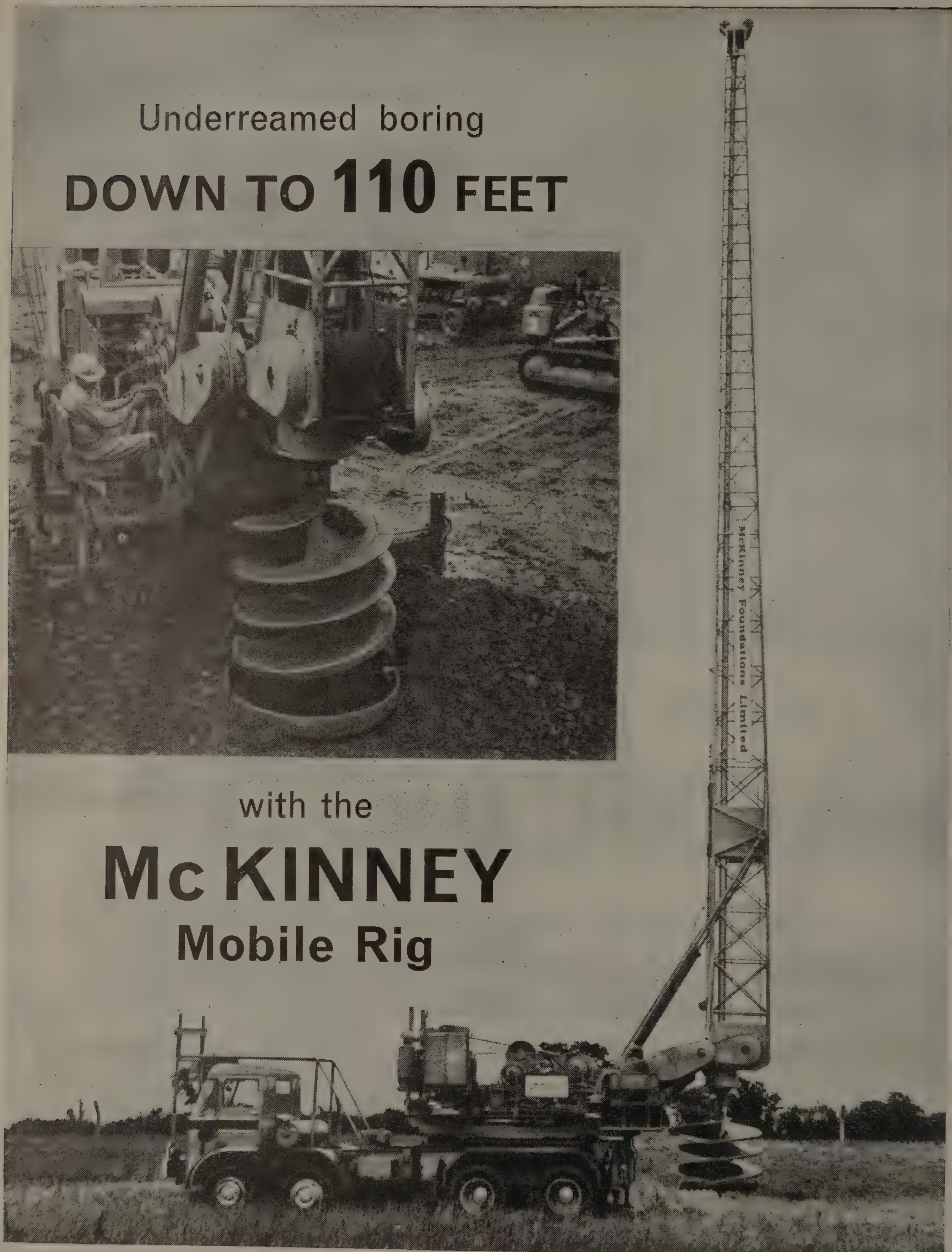
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THE STRUCTURAL ENGINEER

THE JOURNAL OF THE INSTITUTION OF STRUCTURAL ENGINEERS

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CONTENTS

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Mathematics and The Structural Engineer

by E. H. Bateman, M.A., B.Sc., Ph.D., M.I.Struct.E., M.I.C.E., A.M.I.Mech.E., F.R.Ae.S.

The place of mathematics in the profession of engineering science, and engineering design, comes under review from time to time. The most notable contribution of recent years, to this important topic was made by Sir Charles Inglis in a lecture[1] to the Institution of Civil Engineers in December, 1947. His title was a broad one—" Mathematics in relation to engineering "—but that title was abundantly justified by the breadth of his exposition and the illumination of his insight. In this more detailed discussion, of the mathematical needs of a special class of engineers, the field is still very wide and some of the conclusions—if the discussion leads to any conclusions—may be of general interest and application.

But the scope of this enquiry is necessarily more limited for the following reason : the contribution of theoretical analysis may be more significant in one branch of engineering than another, a proposition which was so aptly stated, for a particular case by Sir Alfred Pugsley, when he wrote[2]:—

> " One may say, with little exaggeration, that while the science of electricity largely produced the electrical industry , the steam industry largely produced the science of thermodynamics."

On this basis of comparison, structural engineering may be found to have more affinity with the steam industry than electrical engineering. Many of the aspiring skyscrapers of Manhattan pre-date the analytical method of moment-distribution[3], the plastic theory of design of steel skeletons[4], and the scientific investigation of the composite behaviour of a structural frame and its cladding[5]. Structural engineers will long remember that Gilbert Roberts had completed the " Dome of Discovery "[6] before the results of " exact " calculations were available ; they will long continue to heed his good example, though without denying the value of posterior analysis as a basis for the refinement of design rules for similar structures.

During the past few years, the place of mathematics in the education of structural engineers has been under review by the Council of the Institution, and in 1961 a paper on mathematics will be included in the Graduateship Examination. Some members of the Institution may see in this innovation a threat to exclude the potential designer whose mathematical capacity is limited ; since a talent for design, in the sense of creative invention rather than analytical refinement, is so often incompatible with a talent for mathematics, these two talents being of a different order and quality—almost indeed of opposite polarity. The greater a young engineer's ability in design, the lower may be his mathematical ceiling.

The Mathematical Ceiling

This idea of the mathematical ceiling was introduced in the literature by Sir Charles Inglis, in his presidential address[7] to the Institution of Civil Engineers, in the following masterly and memorable paragraphs, which for twenty years have been a source of comfort, hope, and inspiration to all the members of the " integral-d-raspberry " clubs of our engineering educational faculties :—

> " Mathematics is a subject which differs from almost any other form of knowledge in that to most individuals it presents a ceiling above which it is impossible to rise. When a student is endeavouring to master a particular subject, lack of natural ability can usually be overcome by extra effort ; but my teaching experience leads me to believe that this does not apply to mathematics, and the fact that most students in this subject possess a definite limitation, and are unable to rise above it, does not necessarily betoken a lack of effort.
>
> " Fortunately the mathematical ceiling for most engineering purposes is not very lofty and against this barrier the majority of engineering students need not bump their heads ; but its existence must be recognised in any system of engineering education, and a student's ability should be tested at an early stage. Even if this ceiling is below normal he may yet have the makings of a first-class engineer, but engineering principles must be expounded to him in language of a less advanced mathematical character ; otherwise, at the best, he will be in the condition of ' faint but pursuing,' and at the worst, thoroughly dispirited, he may abandon the chase."

It is to be hoped that this definition of the mathematical ceiling will be remembered if ever there should be a proposal to extend the scope of compulsory conventional mathematics to the Associate-Membership examination. Here the questions may be asked : Who is this writer? What does he know of mathematics? Where is his mathematical ceiling? Such questions are lightly turned aside by quoting Bertrand Russell's justification[8] of his own right to assume the role of commentator on Plato :—

> " It is noteworthy that modern Platonists, with few exceptions, are ignorant of mathematics, in spite of the immense importance that Plato attached to arithmetic and geometry, and the influence they had on his philosophy. This is an example of the evils of specialisation : a man must not write on Plato unless he has spent so much of his youth on Greek as to have had no time for the things that Plato thought important!"

So, on this argument, it must not be assumed that a man is debarred from writing on mathematics unless he has spent so much time on formal mathematics as to have none left for its application to matters of practical importance.

Mathematics and Mathematician

A related question in this context is : What does this writer mean by the word mathematics? Here the word is used in the colloquial sense and not with any esoteric interpretations which may conceivably emerge from profound and prolonged study of the writings of professional mathematicians and philosophers ; in particular, there is no need to go all the way with Bertrand Russell and equate mathematics with pure logic.

Mathematics has sometimes been defined by engineers as the mathematics we don't know, the extensive domain which lies above the individual ceiling. On this subjective definition, what lies below is just arithmetic, lightly garnished with some elements of geometry and perhaps the rudiments of algebra and analysis. What we know, or what we may at any time have been able to apprehend, always looks simple in retrospect, and even in the colloquial sense the word mathematics implies something far from simple. The natural tendency to think of

mathematics as relating more to what lies above the ceiling than below it derives from the close association between the two words mathematics and mathematician. Not only in common parlance but in the literature, a mathematician suggests a man, or a mind, ranging far and high above the humble ceilings of common sense, elementary calculation, and structural engineering. To most engineers, Sir Richard Southwell is a mathematician of high attainment, and eminent, rare, distinction, yet he himself has made it clear that we do him little honour and less justice by this association. On many occasions he has, either directly or by implication, opted himself out of the circle of mathematicians which he presents to us as a closed shop of pure specialists. Thus[9]:—

> "As I believe, every engineer needs to realise that his outlook and that of the mathematician are, in the last resort, irreconcilable ; . . . to maintain that the two outlooks are irreconcilable is not to dispute the validity of either. Mathematics is concerned with ideal concepts, true in any imaginable world ; physicists and engineers seek to understand, and (in some degree) to control a world which imagination cannot alter, a world in which no data are precise. Every engineer has need of mathematics, since design entails computation . ."

Without pursuing attempted definitions too far, there seems to be one kind of mathematician operating in a world of abstract ideas and symbols, but at least two kinds of mathematics. These two kinds may be considered as the mathematics of mathematicians, on the one hand, and of engineers or physicists, on the other ; the mathematics of an ideal world as against the mathematics of the real world (if there is one) ; the mathematics we know (if any) and the mathematics we don't. It may even be reasonable to accept the traditional but not wholly satisfactory dichotomy—mathematics, pure and applied. Logically there are no such distinctions, since every representation of a physical problem by mathematical symbols, and mathematical equations or inequalities, leads at once from the world we know to the world of abstraction and imagination.

The Mathematics Teacher

If, following Southwell, it be assumed that "every engineer has need of mathematics, since design entails computation," the question now arises : Who should teach mathematics to the structural engineer—the mathematics that he will need in the ordinary course of his daily work of design ? The answer must be : Certainly not a mathematician!; if Southwell's definition of a mathematician be taken at its face value. Is there any need for a teacher of mathematics when we must have teachers of "strength of materials" and "theory of structures," whose work depends so much on the use of mathematical processes, many of which may not have been already apprehended and assimilated by the student ?

In a recent college examination paper, of a third-year structural engineering course, the following question was set :—

> "A cantilever of length l carries a load w concentrated at a distance a from the fixed end. By means of the calculus derive a formula for the deflection at the free end."

It was set in a paper on "Mathematics." Here is a question that no mathematician could even attempt to begin to answer, and whatever our definition of this elusive personality, any mathematician must be assumed capable of making short work of a third-year subsidiary paper on mathematics, if it be properly so entitled ; yet this question would be easy meat for the engineering candidate who had been introduced to the elementary theory of elastic flexure, of a beam of uniform cross-section, and remembered the jargon. Although the explanation here must be that the teacher of mathematics and the teacher of engineering were one and the same person, the simple fact that such a question could be, and was, set—in a mathematics exam—is sufficient justification for this discussion.

This example illustrates the absurdity which may ensue from an unwarrantable invasion by the mathematics teacher of the province of the engineering teacher. But what of the converse problem—trespass by the engineering teacher in the field of mathematics? In many teaching institutions, it is accepted practice for the teacher of a branch of engineering science to digress from time to time to explain a mathematical process. Thus Rauscher[10], in his book on Aeronautical Dynamics, which is admittedly the substance of his lecture course, includes a lengthy explanation of a purely geometrical problem ; he does do in a manner which some mathematicians might dismiss as archaic, clumsy, or inelegant, but he has no doubt trimmed his treatment to suit the mathematical ceiling of his class—he uses "language of a less advanced mathematical character," in the Inglis' tradition. There can indeed be no trespass in the field of mathematics by the engineering teacher if he is explaining a mathematical process on which the solution of his engineering problem depends. But what of the mathematics teacher? Must his ambit be limited to the ideal, abstract world of the mathematician? Certainly not. In modern teaching practice, the tendency is to emphasise the applications of mathematics. In the current manual "The Teaching of Mathematics"[11] we are invited to agree with the proposition that "for the purposes of teaching at a lower level such as the average secondary school, the studies classified as mathematics might be described as a collection of methods and results created through solving problems suggested originally by the physical world, but latterly by the results themselves" ; we are invited to remember these "contacts with the external world" no less than the mathematical world of ideas. In this connexion, M. J. Lighthill is reported [12] as having "urged that boys and girls should be trained to apply their mathematics to life and not to regard it as a piece of ceremonial ritual."

Returning to the problem of the loaded cantilever, an examiner in mathematics would not be out of bounds if, in using a cantilever to express his contact with the external world of engineering, he confined himself to formulating a physical relation between load and deflection before asking for a mathematical derivation "by means of the calculus."

It is an open question however whether the mathematics, postulated by Southwell, which an engineer needs for design, would not be better introduced and developed in the course of instruction in engineering theory, than as a separate topic. So to load the engineering teacher with responsibility for "tool-kit" mathematics[13], the mathematical hand-tools of everyday work, would not make the mathematics teacher redundant ; on the contrary it would free him to introduce to the structural engineer the powerful machine-tools of mathematics. This suggestion is left for discussion in a subsequent paragraph under the heading "A mathematical education."

The Mathematics Syllabus

Whatever the answer to this problem of responsibility for mathematics teaching, there should be no dispute as to the scope of a primary syllabus : some

elementary definitions, propositions, and methods of deduction in algebra, trigonometry and co-ordinate geometry ; and a short introduction to the differential and integral calculus. These elements of the mathematical tool-kit are concisely set out in the new syllabus for the Graduateship Examination. The order in which the elements of the syllabus are tabulated is revealing. In "calculus," the first item is "differentiation of simple polynomials and the trigonometric ratios ;" and the second item brings us at once to "the exponential and logarithmic functions and their derivatives." Full marks to those who drafted this syllabus, for this early mention of the exponential function. In many mathematical text-books the exponential function does not appear till very late in the day. The mind of the mathematical student must be conditioned ; his brain must be washed free of all contamination with the external world ; he must be inducted into the mysteries of convergence, semi-convergence, and divergence of infinite series.

G. H. Hardy, for example in his "Course of pure mathematics"[14] gives his reader 356 pages of brain-washing before coming to the logarithmic and exponential functions. He treads very delicately. Having defined the logarithmic function, he proceeds :—

> "We shall now introduce a number, usually denoted by e, which is of immense importance in higher mathematics. It is, like π, one of the fundamental constants of analysis.
>
> "We define e as the number whose logarithm is 1. In other words e is defined by the equation
>
> $$1 = \int_1^e \frac{dt}{t}$$
>
> Since log. x is an increasing function of x, in the stricter sense of para. 95, it can only pass once through the value 1. Hence our definition does in fact define one definite number."

It is a relief to have to read hardly a page more before being actually introduced to the exponential function. Hardy was, of course, the mathematical king of his generation, and his book is destined always to be remembered only with respect and handled with reverence. His method of derivation of the existence and properties of complex numbers is still a source of intellectual delight, even to the mathematical philistine who cannot conceal his impatience with Hardy for so carefully guarding some of the most precious of the jewels in his treasure chest.

Horace Lamb is much more direct, in his "Elementary course of infinitesimal calculus"[15]. On page 35 he writes :

> "We next consider the 'exponential' function. This may be defined in various ways ; perhaps the simplest, for our purpose, is to define it as the sum of the infinite series
>
> $$1 + x + \frac{x^2}{1.2} + \frac{x^3}{1.2.3} + \cdots\cdots"$$

But the reader, who would prefer a derivation to a definition, has to wait till he reaches page 560 before the exponential function is presented as the solution of the differential equation $y = dy/dx$.

Charles Inglis is not only direct ; he is dramatic. The exponential function is introduced[1] with a fanfare of trumpets.

> "Among expansions, the exponential series
>
> $$F(x) = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots\cdots \frac{x^n}{n!} + \cdots\cdots$$
>
> should be awarded the order of merit (first class). In its perfect natural rhythm and in the scope of its application its excellence is unsurpassed. It remains serenely indifferent to differentiation or integration but the property by which it wins our admiration and gratitude is that
>
> $$F(x) \times F(y) = F(x + y).$$
>
> Through this we are given an insight of the way nature performs multiplication, and humanity, following this clue, has evolved the technique of logarithms."

Here, then, are three methods of introducing the exponential function, presented by three of the order of merit (first-class) mathematicians of their generation: the pure mathematician, the applied mathematician, and the engineer-mathematician. To anyone trained as a mathematician in the tradition of Hardy, the early mention of the exponential function in the Graduateship syllabus might seem precipitate and presumptuous, but engineers need have no such qualms. The important point is that it should be possible to raise any doubts about the content, and sequence of topics, in a syllabus of the elements of mathematics.

For nearly two thousand years, in the world of mathematics, there were no doubts raised as to the proper order and precedence of the mathematical theorems and methods then known. Euclid had laid down the law—a presentation in logical order—an order and a logic which remained for so long untouched and apparently untouchable.

The Parnassian staircase which Euclid and his contemporaries created may one day be complemented by corresponding codes in other branches of mathematics. Until that day comes, the wide variety of possible paths and the heterogeneous parade of potential guides must tend to impede the progress of the mathematical pilgrim ; here indeed may lie an explanation of the acknowledged difficulty which otherwise competent students so often experience with the elements of mathematics.

Infinite Series

The enunciation of the exponential series by Sir Charles Inglis, which has just been cited, occurs in a passage in which he commends to engineers other "stars in the mathematical firmament which shine forth with a light of the first order of magnitude."

In this galaxy, as charted for us by Sir Charles, the exponential series is preceded by Fourier's harmonic series and Taylor's polynomial expansion. With characteristic vigour, he sweeps aside the elaborate and deep defences which men like Hardy have set up to guard the more exotic of the flowers that bloom in their mathematical hot-houses. Thus :—

> "The red herring of convergency need not be dragged across the trail. In all the practical cases engineers are likely to encounter, the degree of convergency is controlled by practical considerations, the residue left at any stage having a physical interpretation which reveals how near the truth our approximation has brought us."

The idea and the use of infinite series owe little to modern analysis. Archimedes was fluent in the application of arithmetical and geometrical progressions, and, in effect, he used infinite series to determine the area of a triangle and the volume of a cone or a pyramid[16]. Two of the basic analytical problems of Archimedes' time were the determinations of the square root of a number, and of the cube root, so that similar figures in two dimensions or three could be constructed to any desired proportion in respect of area or volume.

Numerical solutions to many such problems were obtained by the mathematicians of classical Greece and Egypt in the form of infinite continued fractions, products, progressions and series.

The general problem of extracting roots, not only the square root and the cube root but the nth root of a number, is that of evaluating the right hand side of the identity

$$y = a^n \quad . \quad . \quad . \quad . \quad (1)$$

for fractional values of n.

If a solution is proposed in the form

$$y = A_0 + A_1 n + A_2 n^2 + \cdots\cdots \quad . \quad . \quad (2)$$

the unknown coefficients, which are independent of n, can be determined by substituting series of this form in the identity

$$a^m \times a^n = a^{m+n} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

On comparing the coefficients of powers of m and n, on opposite sides of the equation, the following relations appear

$$A_0 = 1\,;\; A_2 = A_1{}^2/2\,;\; A_3 = A_2 A_1/3\,;\text{ etc.}$$

so that every coefficient can be found in terms of A_1. Now, writing λ for A_1, to avoid the suffix,

$$y = 1 + \lambda n + \frac{(\lambda n)^2}{2} + \frac{(\lambda n)^3}{3.2} + \cdots + \frac{(\lambda n)^r}{r!} + \cdots \quad . \quad . \quad . \quad (4)$$

which is the exponential function.

As yet the problem is only half solved, and an expression for λ has to be found, if possible, in terms of powers of a.

Now if $n = 1/\lambda$

$$a^{1/\lambda} = 1 + \frac{1}{1} + \frac{1}{2.1} + \frac{1}{3.2.1} + \cdots\cdots \quad . \quad . \quad (5)$$

and the sum of this series is a number greater than 2 and less than 3, as may be shown quite simply by comparison with the geometric series $\sum (1/2)^r$; this number is the exponential number, denoted by e or ε.

The problem of root-extraction now rests on finding λ from the equation

$$a = e^{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where e has the special property, implicit in (4), that

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{3!} + \cdots\cdots \quad . \quad . \quad . \quad (7)$$

Assuming, as before, a solution in the form,

$$\lambda = B_0 + B_1 a + B_2 a^2 + \cdots\cdots \quad . \quad . \quad . \quad (8)$$

substitution in (6) gives

$$a = e^{(B_0 + B_1 a + B_2 a^2 + \cdots\cdots)} \quad . \quad . \quad . \quad (9)$$

but, on proceeding to determine B_0 by making the obvious substitution $a = 0$, it becomes apparent that an infinitely large negative value of B_0 is required.

Here is a serious stumbling block; the proposed solution in (8) leads nowhere. However, if we could find unity on the left hand side when the right hand side is reduced to unity, by taking a and B_0 both zero, further progress could be made. In fact, a solution in the form (8) can be used to solve the equation

$$1 + b = e^{\lambda}. \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The assumption of a series for λ, in powers of b, leads directly to a solution in the form

$$\lambda = b - \frac{b^2}{2} + \frac{b^3}{3} - \cdots\cdots \quad . \quad . \quad . \quad . \quad (11)$$

which is the logarithmic series.

On making the substitution $1 + b = a$, the solution of (6) appears in the form

$$\lambda = (a-1) - \tfrac{1}{2}(a-1)^2 + \frac{1}{3}(a-1)^3 - \cdots\cdots \quad . \quad . \quad . \quad (12)$$

The problem posed by equation (1) is therefore solved for all values of a in the range $1 < a \leqslant 2$; and if $a > 2$ the solution can still be applied by expressing a in the form $2^n p$ where $1 < p < 2$.

On this argument, the exponential series precedes the logarithmic and both precede the calculus, a complete reversal of the order developed by Hardy and mathematicians of his school; but our direct and elementary approach assumes that an infinite series is not necessarily a dangerous reptile with a poisonous sting concealed in its long tail.

The Mathematical Trick or Subtlety

The methods of Euclid and Archimedes, of finding series solutions for their problems, have been shown to lead directly to the discovery of the exponential and the logarithmic series. It is interesting to speculate on whether or not these series were known over two thousand years ago; for, as Turnbull has noticed[17,18], the rule of indices, epitomised in equation (3), is implicit in some of the numerical theorems in the ninth book of Euclid's Elements.

A plausible hypothesis is that the exponential series was so known; but not the logarithmic. If that were in fact the case, it would seem that the development of mathematical analysis lay in a deep freeze for well over a thousand years for lack of a simple mathematical trick—the use of equation (10) to overcome the stumbling block posed by the incompatibility of equation (9).

Such mathematical tricks or subtleties are obviously necessary to progress in mathematics. Unfortunately, however, mathematics to-day seem to depend so much on a limitless collection of such subtleties that the mathematical student can hardly see the wood for the trees; and not only the student but some teachers and text-book writers too.

Inglis has suggested[1] that the exponential series gave humanity the clue to the discovery of logarithms. It is beside the point to remark that Napier made this discovery by a less direct method, as is clear from the account given by Bromwich [19] in an appendix to his "Infinite Series." Even Sir Isaac Newton, whose methods of investigation have been critically surveyed by Andrade[20], made intuitive discoveries for which he was sometimes hard put to find rigorous proofs.

In the exposition of mathematical theory and the development of teaching methods, there is a crying need for more highlighting of mathematical landmarks and signposts; for a significant degradation of the importance attached to mathematical tricks and subtleties.

The trick or the subtlety may still be the key to progress in pure mathematics, but it should not be the key to examination success for the engineering student. For him there should be no premium on ability to memorise the currently favoured collection of mathematical tricks, but rather a dictionary of mathematical tricks, devices, stratagems, subtleties and standard solutions, which he may take with him into the examination room as he does his mathematical tables and codes of design practice.

Infinity

In the study of mathematics, the notions most difficult to apprehend and assimilate are not always those associated with the most advanced or sophisticated discussions. There are difficult notions within

the scope of an elementary syllabus. One of the modern "pontes asinorum" in the path of the mathematical novice is the so-called imaginary part of a complex number. Quoting Inglis[1]—yet once more: "The idea of the square root of minus one puts a strain on one's power of imagination; it is an abstraction which would hardly find its spiritual home in an accountant's office."

Even more difficult is the idea of infinity. Yet it need not be difficult; it has been made unnecessarily difficult by the treatment which infinity has been given, in recent times, by mathematicians, and by their mutual contradictions and controversies.

Hardy[14] gives us a very sound start:— "There is no number 'infinity'; such an equation as $n = \infty$ is as it stands absolutely meaningless; n cannot be equal to infinity because 'equal to infinity' means nothing."

Bromwich[19] has no such scruple about "such an equation," for he consistently equates to infinity the "limit" of a function. Thus, either he begs the question of a definition of "limit" or he bedevils the conception of infinity as enunciated by Hardy. It may be possible to justify this usage of Bromwich as a piece of convenient shorthand, but this is a matter in which it is important to be scrupulous.

Bertrand Russell goes further away from Hardy's conception of infinity; indeed in his "Western Philosophy" he seems to travel an infinite distance from both Hardy and common sense, when he writes on page 854:—

> "The number of finite whole numbers must, therefore, be an infinite number. But now comes a curious fact: the number of even numbers must be the same as the number of all whole numbers. Consider the two rows:—
>
> $$1,\ 2,\ 3,\ 4,\ 5,\ 6, \ldots\ldots$$
> $$2,\ 4,\ 6,\ 8,\ 10,\ 12, \ldots\ldots$$
>
> There is one entry in the lower row for every one in the top row; therefore the number of terms in the two rows must be the same, although the lower row consists of only half the terms in the top row. Leibniz, who noticed this, thought it a contradiction, and concluded that, though there are infinite collections, there are no infinite numbers. Georg Cantor, on the contrary, boldly denied that it is a contradiction. He was right; it is only an oddity."

It would not be necessary to mention this aberration of Bertrand Russell, if the error had not permeated and poisoned the literature of infinite collections and infinite series. Even Hardy indirectly lent the great weight of his authority to this fallacy by his acceptance of the widely adopted notion of a "conditionally convergent" series. On page 341 of Pure Mathematics[14] the following example heading appears in bold type: "Alteration of the sum of a conditionally convergent series by re-arrangement of the terms." The implication of this heading is that the infinite series

$$1, -\frac{1}{2}, +\frac{1}{3}, -\frac{1}{4}, +\frac{1}{5}, \ldots$$

is the same as the infinite series

$$1, +\frac{1}{3}, -\frac{1}{2}, +\frac{1}{5}, +\frac{1}{7}, -\frac{1}{4}, \ldots$$

but that the sum of the terms is altered by derangement of the order of the terms. It is nonsense to say that the sum of a simply alternating series is altered by taking "two positive terms followed by one negative term"; for, by such a derangement, the original series is destroyed and a new one substituted. No valid conception of infinity, or of the so-called transfinite numbers, can be based on the proposition that we should find the same number of negative as of positive terms in the second of these series if only we could count far enough.

If then the mathematical pundits have not yet achieved a consistent and comprehensible definition of infinity, how should the structural engineer attain enlightenment? Fortunately, for most engineering purposes, infinity lies close to hand. One has but to cast the mind back to the days when we first began to count:— "One, two, three . . . lots!" There, in the nursery, is a clear if embryonic motion of infinity. The engineer in practice rarely needs to go much further in his approach to infinity; whether he is representing a periodic function by its harmonic components, evaluating a series solution, or assessing a structural design by the method of moment-distribution.

A Mathematical Education

So far this discussion has touched the manner rather than the substance of a mathematical education. The order in which mathematical ideas should be presented to the engineering student and the way in which they should be expounded to him have been surveyed, as has the percentage of mathematical purity to be desired in his teacher. This survey would be incomplete without some attempt to indicate, if not precisely to define, the proper field of interest for a structural engineer.

The bare notion of a mathematical education is unfamiliar, although no claim to originality in the use of the term could be established without an extensive library investigation. Definitions are difficult; it is hard to define a mathematical education in the single sentence which is so essential for a dictionary or a glossary. The intention here is to suggest a view of mathematics designed to open a prospect beyond the range of the next examination in theory of structures or strength of materials. It may well be desirable to relate some of the mathematical instruction to the practical needs of the engineering courses; a case may even be argued for the procedure in which a versatile teacher, having reduced an engineering problem to a mathematical equation, closes his lecture with the reminder that he will retire for five minutes to don his mathematical hat, and return to solve the equation in his mathematics lecture. But, if a mathematics course is so planned as a subsidiary and servile appendage of the engineering course, no advantage will have been gained by its introduction as a special item in the syllabus. The recognition of mathematics as an independent element of an educational course should be seen as the opportunity and the cue to laying the foundations of a mathematical education.

An education in mathematics should transcend the ability to produce solutions of conventional problems, the facile expertise of a successful examination student working in a very small prescribed path of well-charted mathematical territory. There is a parallel here with a musical education, which goes far beyond the mechanical facility of technical accomplishment on a particular instrument. On another analogy, a military education may begin with small-arms drill, but it extends to tactics, strategy, logistics, history and psychology. The five-finger exercises and the small-arms drill of mathematics may be a necessary prelude to a mathematical education, but a modest proficiency in these elements should not be the end of the matter.

An outline of a mathematical education is most simply indicated by listing some of the topics which should be brought to the notice of the engineering

student. Sir Charles Inglis, in the lecture[1] to which several references have already been made, gave prominence to Harmonic Analysis, Taylor's Polynomial Expansion, and Conjugate Functions; he advocated graphical integration, the power-series method of solution of differential equations, and vector representation of the solutions of problems of mechanical vibrations. To this short list of relevant topics, we should now add Matrix and Vector Algebra, the Operational Calculus which is still being developed from the inspiration of Oliver Heaviside, Numerical Analysis, and the elements of Statistics. One need add only a few more such topics, it will be said, to form the syllabus not of a subsidiary intermediate course, but of an honours degree in applied mathematics. And so it would be if every such topic were studied with the intensity, and to the extent, that may properly be required of a mathematical specialist. But the purpose of education is not merely the assimilation of knowledge and the perfection of technique. More important is often the ability to appreciate a situation or assess a problem, to know where to look for a solution or to which specialist to turn for advice.

In the limited time available in an engineering curriculum, it is no doubt necessary to relate a view of mathematics to the types of application with which the students is likely to be concerned in his professional practice after graduation; but, since the ultimate destiny of a student is unpredictable, this view should be taken as widely as possible. The obvious objection to such an attempt to widen the scope of a mathematical syllabus, at the expense of technical proficiency in mathematical manipulation, is the difficulty of devising a suitable examination. But no progress in education can be made if our educational system is to be indefinitely modelled on the pattern of the nineteenth century, when the field of interest was so much more restricted.

Recently Mr. D. A. G. Reid, an educationalist of experience, responsibility, and authority, has referred to the place of mathematics in the education of a structural engineer. In his paper on "Technical Education and Professional Training"[21], a synoptic survey of the whole field, his only reference to the "details of curricula and syllabuses of engineering course" was as follows :—

> "The core of the academic discipline of an engineering course is mathematical and the real difficulties of a large majority of students in such courses are mathematical." . . . "It is open to doubt whether the chances of a man's qualifying as an engineer should, to so great an extent, depend on his capabilities as a mathematician and current developments in engineering practice are tending to increase this doubt. Educational and professional institutions alike seem unwilling to experiment with the fundamentals of engineering courses though the nature of abilities in engineering practice grows constantly more diverse. This is a problem which engineering institutions must study . . ."

Had this penetrating and challenging epitome been published earlier, it would have made an apt text for these present notes; in retrospect it affords ample justification for this discussion of the mathematical needs of structural engineers.

Conclusions

The adoption, by the Institution, of a compulsory examination in mathematics should not be applied in such a way as to exclude from membership potential designers who may have a low mathematical ceiling.

Progress in some branches of structural engineering science may depend on the application of mathematical methods, but such applications should be left to mathematical specialists; the scope of structural engineering is so wide that there is room for a number of diverse specialities.

Conventional methods of mathematical teaching are often unnecessarily abstract, indirect, and artificial; they may to some extent be responsible for the admitted mathematical difficulties of many engineering students.

Too high a premium is often put on ability to memorise mathematical tricks and subtleties, when a solution could be obtained by straightforward application of a general mathematical process, such as the power-series method for differential equations.

Students should be "trained to apply their mathematics to life and not to regard it as a piece of ceremonial ritual"[12], but such applications should not be invariably related to the requirements of an engineering course.

One of the objects of a mathematical education should be to introduce students to the machine-tools of mathematics, both theoretical and practical, without necessarily the know-how of detailed application, to give them an appreciation of the power of mathematical methods and a knowledge of when to seek specialist advice.

The progress of structural engineering science owes much to mathematics and applied mathematicians, but mathematicians may yet have to look to structural engineers for a lead to progress in the teaching of mathematics.

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[NOTE : This Paper was received in February, 1959.]

Discussion

The Council would be glad to consider the publication of correspondence in connection with the above paper. Communications on this subject intended for publication should be forwarded to reach the Institution by the 30th June 1960.

The Use of Semi-Graphical Methods in the Stress and Deformation Analysis of Shell Forms

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SYNOPSIS

The modern shell structure has to withstand internal and external pressures together with forces acting on the surfaces over relatively small areas. The advent of the large containment vessels in the field of Nuclear Power Engineering (for example the Dounreay Sphere) introduced the need for a closer examination of the stresses and deformations in regions such as the sphere to cylindrical skirt connection and in the vicinity of lugs and various other attachments to the shell. The variety and relative complexity of the design problems encountered call for a flexible method capable of application to stress and deformation analysis over a wide field.

The paper presents a semi-graphical method of analysis incorporating an influence line concept, based on the behaviour characteristics of shallow spherical domes subjected to isolated load actions as analysed by Reissner, Bijlaard and others. The method of analysis proposed is substantiated by the results of an experimental programme which are fully described and discussed. The subject matter is arranged so as to be suitable for design office use and illustrative numerical calculations are included in the Appendix.

Although the work has been primarily directed to the analysis of spherical containment vessels, it is shown in the text that the method proposed is of wide application and may serve as a rational approximation to the analysis of shells other than spherical form.

INTRODUCTION

Any reader of the very extensive published literature on shells and shell-like structures (NASH 1954) is likely to be impressed by two features :— the abundance of theoretical analysis and the paucity of experimental investigations.

The theoretical analyses, although numerous, are severely restricted in that rigorous solutions are available only in a limited number of cases which exhibit some form of symmetry of shell and/or loading. Further, the methods are invariably difficult in their application to particular design problems and are generally not substantiated by systematic experimental work.

The advent in particular of the large spherical containment vessels in the field of nuclear power engineering has created an urgent need for a relatively flexible method of analysis, capable of wide application to the many unconventional stress and deformation problems which have arisen in this field.

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With this background in mind a programme of research was initiated at the Royal College of Science and Technology, Glasgow, sponsored by the Motherwell Bridge and Engineering Co. directed towards the development of rational methods of analysis of the effects of load actions on shell forms. The programme undertaken consists of two main parts. The first embraces the analytical and experimental investigation of the stresses and deformations in spherical shells due to radial and tangential load, bending moment and torque respectively. The experimental work is being carried out on shallow spherical domes instead of complete spheres. This is permissible as the stresses and deformations which arise from isolated actions die out fairly rapidly with distance from the point of application of the load. Consequently as long as the spherical cap or dome investigated is sufficiently large for this ' die out ' to occur well within its boundaries the results obtained are directly applicable to complete spheres.

The second part of the research programme deals with the stresses and deformations which obtain in complete shell assemblies. The construction of a 1/10th scale model of the Dounreay containment vessel (model sphere diameter 13 ft. 6 in.), incorporating a 200 ton capacity loading device is nearing completion. The set up will permit the simulation of typical load, pressure and temperature conditions which arise in such containment vessels and the model will be extensively strain gauged (with around 700 electrical resistance gauges) to evaluate the stresses and deformations corresponding to the imposed conditions. It is hoped that by the autumn of 1960 representative test results will be available.

The paper presents the first completed portion of the research programme, consisting of (i) a method of stress and deformation analysis based on an influence line concept considered of general application to shell forms and (ii) an experimental substantiation of the method in the case of shallow spherical domes subjected to a variety of radial load actions.

The analysis employs as its starting point the effects of a ' unit ' action (load, shear, moment or torque) on a shallow dome and in the cases discussed in the paper the relevant results of E. Reissner's work (REISSNER, 1946) were utilized to provide this. Reissner analyses the bending and membrane stresses and radial deflections in a ' shallow ' dome of infinite extent subjected to a radial load acting at the crown of the dome uniformly distributed over a circular area. This analysis is not reproduced in the paper, since it is one of the best known and acknowledged classics of shell literature. The relevant theoretically derived variations based on Reissner's work are presented in graphical form

directly utilizable for design in Part I, the experimental results fully substantiating these graphs being given in Part II of the paper.

Other theoretical analyses which may be employed to give the effects of the unit actions referred to above are those of P. P. Bijlaard (BIJLAARD, 1956) which treat the effects of radial load and moment acting on a 'rigid' circular insert at the crown of a shallow dome of infinite extent simply supported around its periphery. Further work referred to in the paper is that of J. Chinn (CHINN, 1958) who gives the rigorous solution for the effects of a uniformly distributed ring load on a shallow dome. Chinn's work at Cornell University, U.S.A. — which was made available by courtesy of Professor Bijlaard to one of the authors—is of particular interest. An extension of his work deals with an 'influence surface' concept for spherical domes not dissimilar to the ideas put forward in this paper and is indicative of an intriguing coincidence of the development of independent engineering thought on the two sides of the Atlantic.

In rounding off this introduction the authors hope that they may be forgiven if they refer to a regrettable tendency of the times which has become the characteristic of many research publications in numerous fields namely that of 'the specialist writing for the specialist.' Shell literature is not exempt from this and in many papers a preference for elegance in the mathematical methods used is too often permitted to override the basic requirement of clarity and simplicity of expression. This tends to make the results, in particular of theoretical research, unintelligible to today's designers. Keeping in mind that Engineering is a creative art, research must be considered as having failed in its *engineering* aim unless its results are carried beyond the fundamental aspects to that of constructive design. This can best be achieved not by the creation of a class of designers of specialist understanding in the future, but rather by the translation of research results into design data of a form which is both understandable and usable by the designer of today.

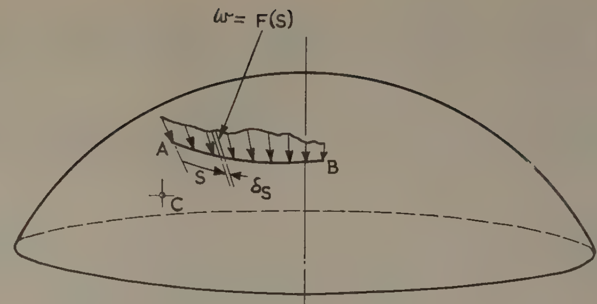
An attempt has been made in the presentation of the paper to achieve this aim, by emphasising basic design curves and graphical methods and including numerical examples worked in detail in place of the cumbersome generalised symbolic expressions so often encountered in publications on shell analysis.

PART I—THE INFLUENCE LINE METHOD

The basic concept can best be outlined in a qualitative manner with reference to the determination of deformations such as radial deflections of a shell, which are relatively easier to visualize than say the distribution of stress actions. The method naturally is of general application as regards the analysis of both deformations and stress actions.

Consider a radial line load of varying distribution acting on the surface of a shell along the path AB as shown in Fig. 1(a). It is required to obtain the radial deflection at a point C on the surface of the shell.

Assume that the load w is removed and a *unit* concentrated radial load is applied at C and that the radial deflections due to this *unit* load along the path AB can be evaluated and are known as shown in Fig. 1(b). If elastic behaviour obtains, Maxwell's Reciprocal theorem applies and the distribution of deflection along AB due to the unit load at C gives the variation of deflection at C as a unit load is successively applied at each point along the path from A to B. Thus it is seen that the



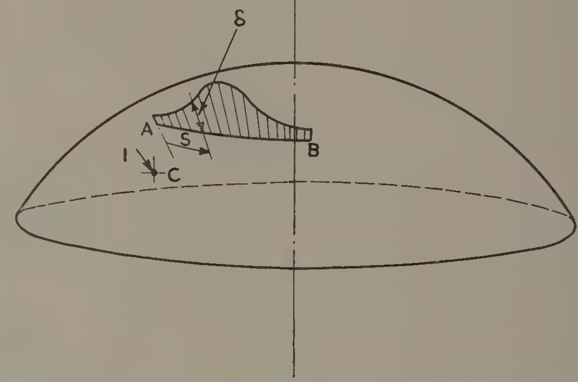


Fig. 1 (a).—Line load along AB of varying distribution on spherical shell.

Fig. 1 (b).—Radial deflections on AB due to unit load at C.

deflection diagram of Fig. 1(b) is in fact the influence line for deflection at C.

Consequently the deflection at C due to the loading w becomes

$$\Delta_c = \int_A^B w\delta ds = \int_A^B F(s)\delta ds.$$

The integral represents the area from A to B under a curve obtained by multiplying each ordinate of the load distribution with the corresponding ordinate of the influence line and can be evaluated by direct integration or in cases of irregular loading or irregular shells by graphical, semi-graphical or numerical means.

If the load w is not a 'concentrated' line load but acts over a finite width d, this can be catered for sufficiently accurately in design analysis, by applying the unit load at C not as a concentrated load but distributed over a circular area of diameter d.

If the load w acts over an area rather than a line path, a series of similar influence lines covering the load area and providing an influence surface can be derived. The integral effect at C is then obtained as the volume between the shell and a surface derived by multiplying each load ordinate by its appropriate influence ordinate, the evaluation again being carried out by any convenient means.

The basic advantage of the method in addition to its obvious flexibility in handling any type of load action is, that the primary analysis necessary is always that of a unit load, or moment or torque as the case may be, concentrated or distributed over a small area. The analyses of a number of such unit actions for cylindrical and

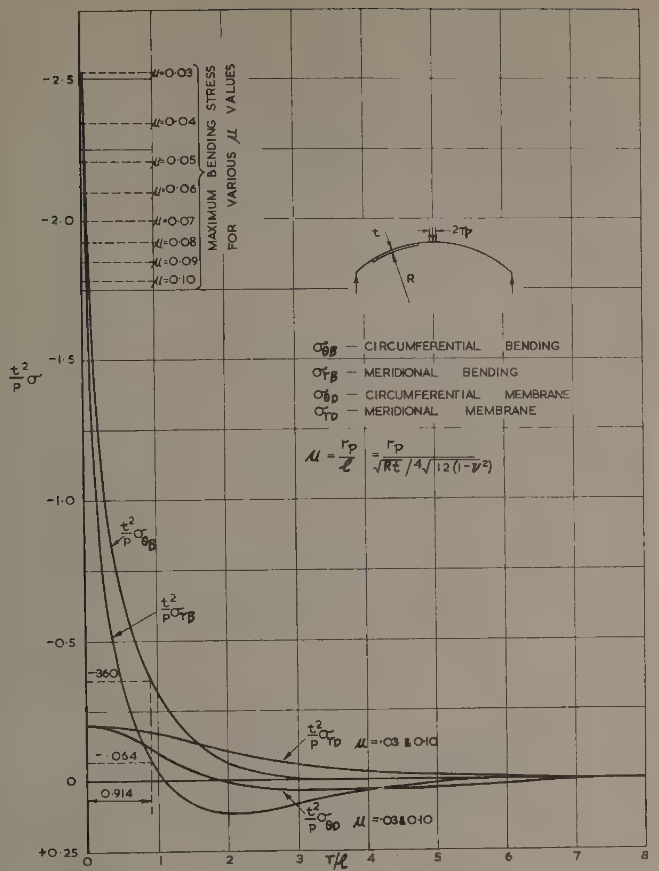


Fig. 2.—Membrane and bending stresses on outer face of shell caused by a load *P* uniformly distributed over circular areas, such that $\mu = r_p/l = 0{\cdot}3$ in increments to $0{\cdot}10$.

spherical shells are available in the references mentioned and may be used directly as outlined above. In the case of spherical shells, for example, Reissner evaluates the effects of a radial load *P* uniformly distributed over a circular area of radius r_p acting on a shallow spherical dome. The relevant curves showing the distribution along a line of symmetry of the radial deflection, bending and membrane stresses are shown in Fig. 2 and 3, in non-dimensional form. The symbols which appear in these figures and not already defined have the following meaning ;— R = Mean radius of shell, t = thickness of shell, r = radius to any point on the loaded surface of the shell measured in plan from the crown, E = Young's Modulus, v = Poisson's ratio,

$$l = \sqrt{Rt}\Big/\sqrt[4]{12\,(1 - v^2)},\ \mu = r_p/l.$$

$\sigma_{\theta B}.\sigma_{rB}$ = circumferential and meridional bending stresses, $\sigma_{\theta D}.\sigma_{rD}$ = circumferential and meridional membrane stresses.

From these curves putting $P = 1$ and determining the values of 'μ' and 'l' appropriate to the shell considered. the unit actions corresponding to a radial unit load may be obtained. A numerical example illustrating the use of the influence line method is given in the Appendix. This treats the case of a ring load of $5\frac{1}{2}$ inches mean diameter and $\frac{1}{4}$ inch wide load path acting on a 10 ft. diameter steel spherical dome of $\frac{1}{4}$ inch wall thickness. This example has been chosen because both experimental results and a rigorous theoretical solution by Chinn are available for comparison. Stresses and radial deflections due to the ring load have been obtained by means of the influence line method along a great circle of symmetry of the sphere, and these are shown in Figs. 4 and 5 compared with Chinn's theoretical values for a line load. It is seen that excellent agreement obtains the slight difference in the region of the ring load being due to the allowance made for the load path width in the influence line method, as opposed to Chinn's treatment of a concentrated line load.

It is relevant to point out here that the influence of the factor 'μ' as seen in Figs. 2 and 3, is primarily manifested at small r/l values, the curves at higher values of r/l practically coinciding. For most practical cases of shell construction the values of 'μ' lie between $\mu = 0{\cdot}03$ and $0{\cdot}10$. It will be seen from Figs. 2 and 3 for this range of values, that only the bending stress curves show any noticeable variation as different 'μ' values are considered. It would therefore appear permissible for this range of 'μ' values to use envelope curves for deflections, membrane and bending stresses. In the case of the bending stress curves, the maximum height of the curve is more sensitive to the changes in 'μ' value. The maximum bending stresses for a range of 'μ' values from $0{\cdot}03$ in increments of $\cdot 01$ to $0{\cdot}10$ are shown in Fig. 2. The complete bending stress curve for any 'μ' value within the above range is then obtained by using the envelope curve up to the relevant maximum.

There is a further point of interest which permits the application of the method outlined as an approximation to shells other than cylindrical or spherical form. The effects of a load acting at a point or small area on a plate structure die out fairly rapidly with distance from

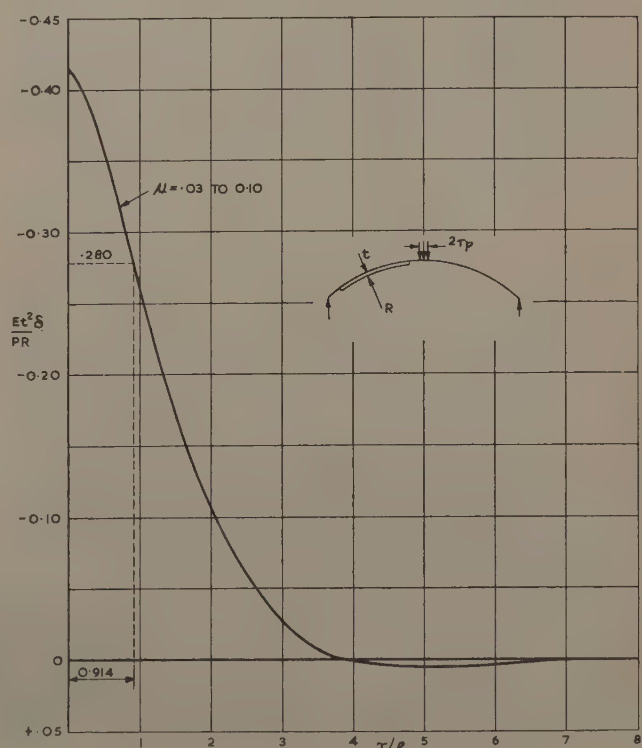


Fig. 3.—Radial deflection δ of the shell caused by a load *P* uniformly distributed over circular areas such that $\mu = r_p/l = \cdot 03$ to $0{\cdot}10$

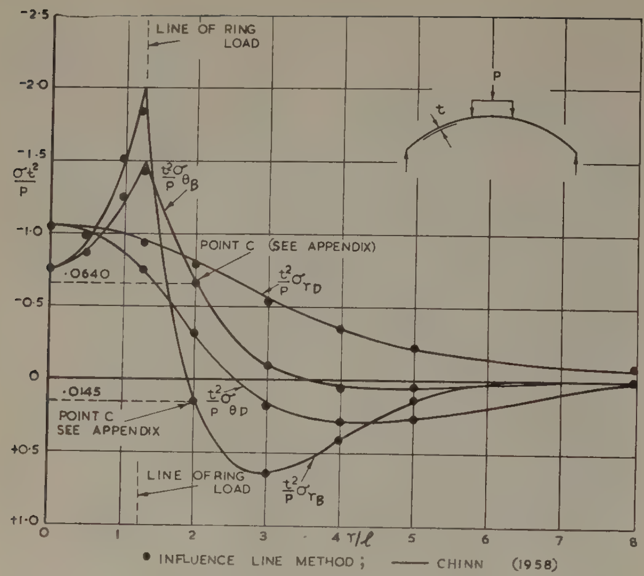


Fig. 4.—Membrane and bending stresses on outer face of $\frac{1}{4}$ in. thick shell due to a ring load P, of $5\frac{1}{2}$ in. mean diameter

the point of action. This implies that the analysis of the effect of the unit action is influenced primarily by the shape of the shell at, and in the near vicinity of, the point where the unit action is applied. Generally the shape of any shell, provided it is of relatively large radius of curvature, can be approximated to in a localised region by that of a spherical or cylindrical segment, enabling the designer to utilize the unit action forms derived for such regular shells in the analysis of irregular forms.

If the shell is of such a form that this approximation is not permissible and no analysis of the unit actions is possible, recourse may be had to model experiments from which the appropriate influence lines can be obtained empirically.

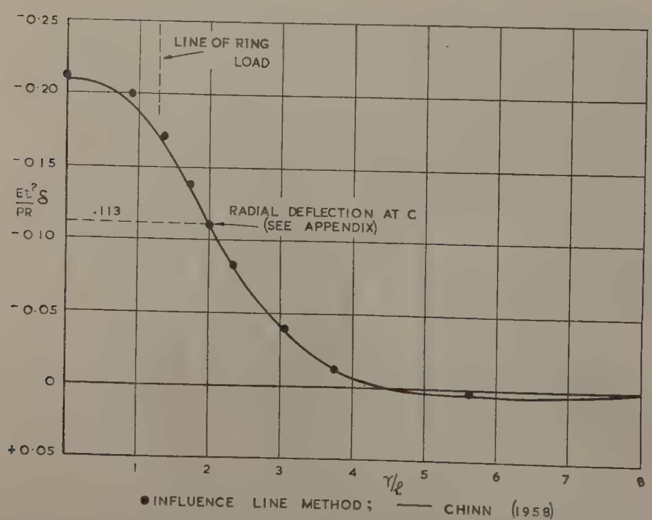


Fig. 5.—Radial deflection δ of $\frac{1}{4}$ in. thick shell due to a ring load P of $5\frac{1}{2}$ in. mean diameter.

PART II—EXPERIMENTAL INVESTIGATION OF SHALLOW DOME BEHAVIOUR

The experimental work has been directed towards the critical evaluation of the applicability of Reissner's (1946) and Bijlaard's (1956) theories for the behaviour of shallow spherical domes under a rotationally symmetrical radial circular area load, and to that of the influence line method exemplified by the problem of a ring load of finite width.

Shallow domes under a radial load uniformly distributed over a circular area

The experimental work has been carried out on shallow domes of 1 inch and $\frac{1}{4}$ inch thicknesses and of 60 inch minimum radius (Fig. 6). The domes have been subjected to radial load, uniformly distributed over areas of various diameters. On the 1 inch thick dome these areas were of $1\frac{1}{4}$, $2\frac{1}{2}$, 5, $7\frac{1}{2}$, 10 and 12 inches diameters, the $\frac{1}{4}$ inch thick dome being subjected to the same loaded diameters together with a $\frac{1}{4}$ inch diameter load. Circumferential and meridional strains were measured on both the upper (loaded) and lower surfaces by means of paper backed electrical resistance strain gauges positioned along a radius, earlier tests having established the rotational symmetry of the shell. Radial deflections were measured along a great circle by dial-gauges reading to 0·0001 inch.

The technique of applying a uniformly distributed load was varied to suit the magnitudes of the loads required to produce measurable strains. In the case of the 1 inch thick dome, the loading device consisted of a piston acting on steel shot contained in a cylinder the shot itself being the loading medium between the piston and the dome (Fig. 6). Measurement of strains was restricted to the region outside the loaded area as attempts to obtain reliable readings from gauges under the load and in contact with the shot were unsuccessful. In loading the $\frac{1}{4}$ inch thick dome an alternative loading technique was adopted permitting the measurement of strains both inside *and* outside the loaded area

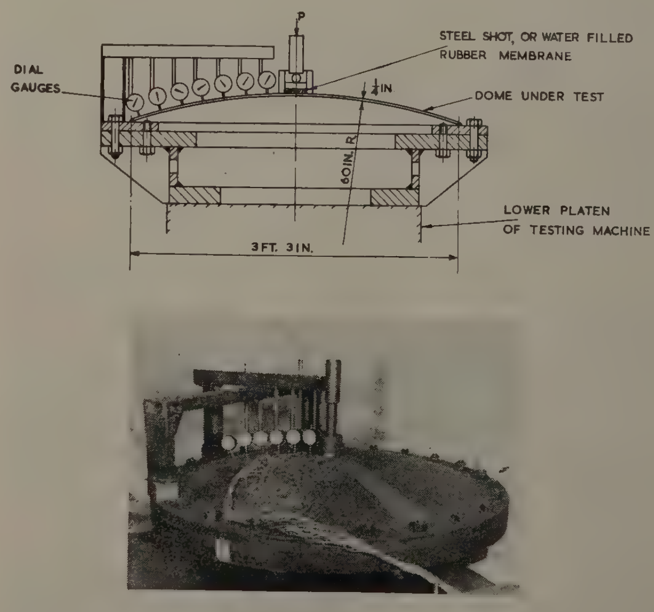


Fig. 6.—Shallow dome test arrangement showing loading device and dial gauge rig.

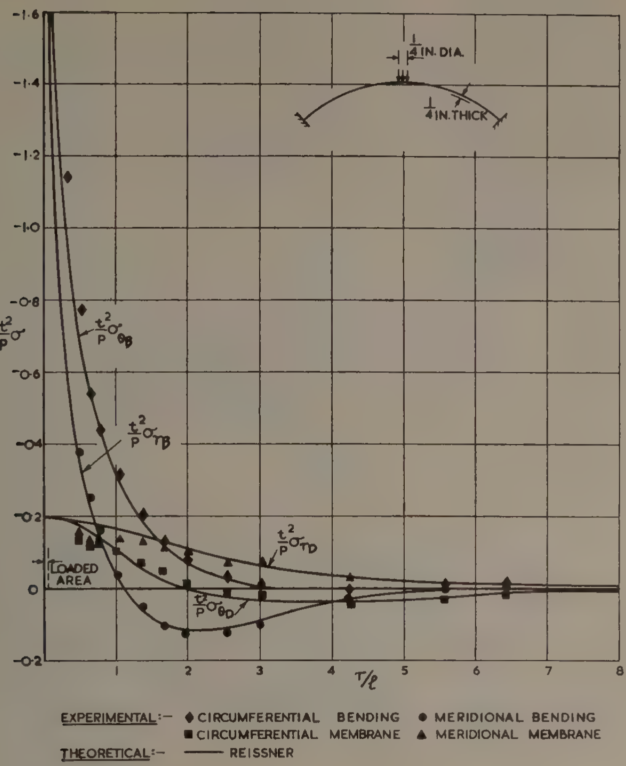


Fig. 7.—Membrane and bending stresses on outer face of $\frac{1}{2}$ in. thick shell caused by a load P, uniformly distributed over a circular area $\frac{1}{4}$ in. diameter.

owing to the considerably lower loads required to produce measurable strains. The shot in this case was replaced by water contained in a thin rubber membrane and the gauges under the rubber membrane performed satisfactorily. Tests were carried out to estimate the effect of normal pressure on the characteristics of the strain gauges and it was found that under the pressures encountered during testing these effects were very small and could safely be neglected.

From the experimental values of the two principal strains, values of the bending and membrane stresses in both the circumferential and meridional directions have been plotted. Comparison of all uniformly distributed load results has been made with the shallow dome theory as put forward by E. Reissner. All tests on both the 1 inch and $\frac{1}{4}$ inch domes substantiate the above theory, for stresses and deflections, agreement being particularly good in the case of small loaded areas. It is suggested that the small deviations in the case of the larger areas may be due to the effects of end fixity met with in the model dome and not allowed for in the analysis. The experimental results for the 1 inch and $\frac{1}{4}$ inch thick domes plotted on Figs. 7, 8 and 9 show the degree of agreement obtained with the theoretical curves.

The deflections due to the area loads have also been compared with the theory of P. P. Bijlaard which considers the uniformly distributed loads to be applied to the dome by means of a rigid insert. It will be noted, (Fig. 9) that such a theory predicts slightly lower values of deflection. Comparison with Bijlaard's predicted stress values has also been made. This is not included in the graphs presented, in order to avoid overcrowding in the figures. The curves of Bijlaard follow the same general trend as those of Reissner, though the experimental values agree more closely with the Reissner curves—this was anticipated as the experimental set up for load application does not constrain the deformation of the loaded area of the dome, and so approximates more closely to the assumptions of Reissner's theory.

Shallow domes under a radial ring load

The experimental work was extended to include the case of a rotationally symmetrical ring load of finite width. The object of this work was to provide experimental results for a case of loading for analysis by means of the influence line method. Ring loads of $\frac{1}{4}$ inch widths and of mean diameters 3, $5\frac{1}{2}$, 8, $10\frac{1}{2}$ and $12\frac{1}{2}$ inches were applied to the $\frac{1}{4}$ inch thick dome. Rings were machined providing a $\frac{1}{4}$ inch wide projection, and were loaded as shown in Fig. 10. 'Prestik' was used between the ring and the dome, to accommodate any slight irregularity in the surface of the dome.

As previously the surface strains and radial deflections were measured. Typical graphs of bending and membrane stresses and deflections are shown in Figs. 11 and 12. The results given are for the case of the $5\frac{1}{2}$ inch mean diameter ring load and these are compared with

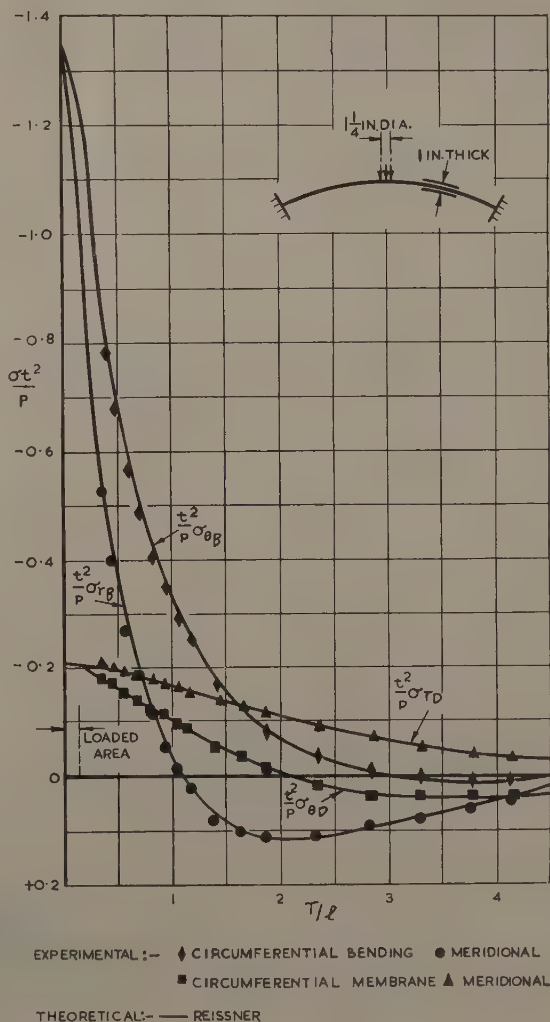


Fig. 8.—Membrane and bending stresses on outer face of a 1 in. thick shell caused by a load P, uniformly distributed over a circular area $1\frac{1}{4}$ in. diameter.

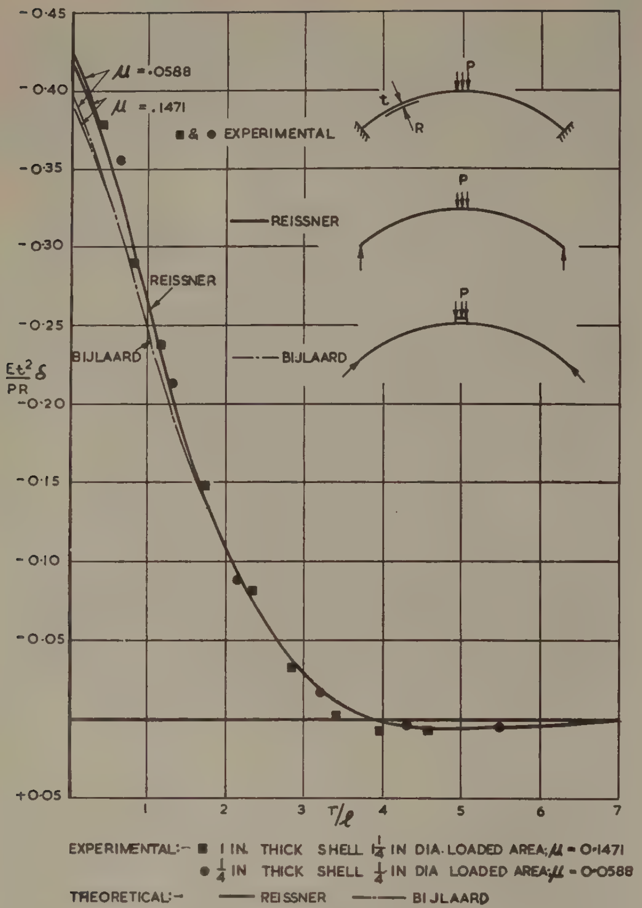


Fig. 9.—Radial deflection δ of the shells caused by a load of P uniformly distributed over two different circular areas.

appropriate values, derived by the influence line method as outlined in the paper. The experimental stresses and deflections show good agreement with the influence line method for the region outside the loaded ring. Inside the loaded ring, and immediately under

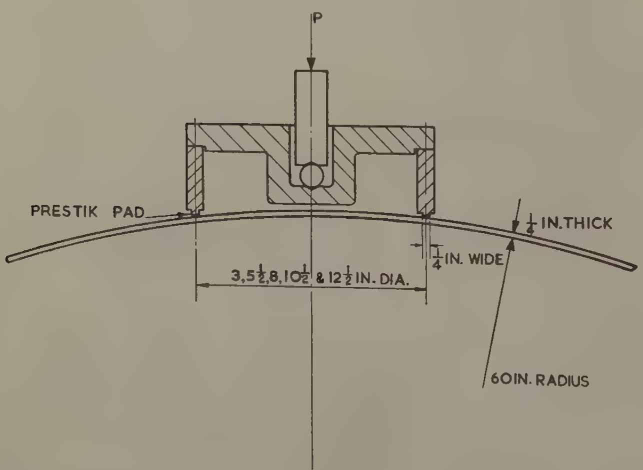


Fig. 10.—Detail of ring loading device for various diameters of ring.

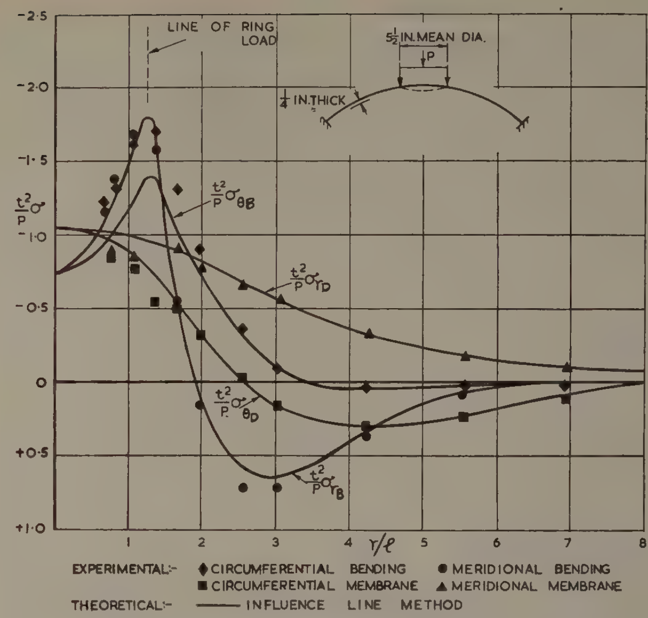


Fig. 11.—Membrane and bending stresses on outer face of ¼ in. thick shell due to a ring load of 5½ in. mean diameter.

the load the circumferential bending stresses show divergence from the analytical due to the experimental difficulty of ensuring complete freedom of constraint at the load point.

Summary

An experimentally substantiated semi-graphical method of stress and deformation analysis is presented applicable to a variety of problems associated with the design of spherical and other forms of shell assemblies. The method, which appears to be of exceptional flexibility, is illustrated, in a form suitable for design office use, by a numerical example of the analysis of a ring load acting on a spherical dome.

Another example of its application, that of the determination of the redundant interactions between a sphere and the cylindrical skirt supporting it, has been previously published in a discussion contribution by Kenedi and Tooth (HICKS, 1958).

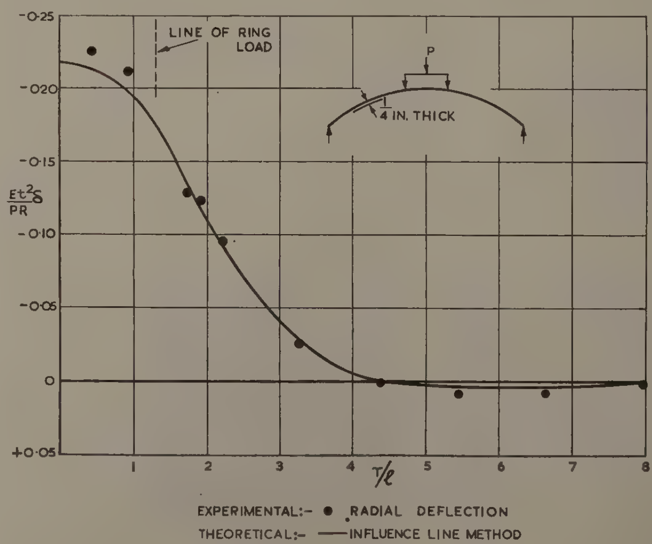


Fig. 12.—Radial deflection δ of ¼ in. thick shell due to a ring load P of 5½ in. mean diameter.

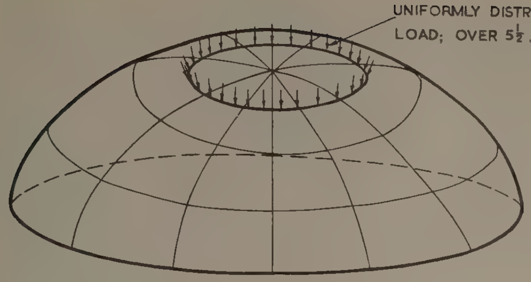


Fig. 13.—The spherical dome ¼ in. thick and 60 in. radius, subjected to a radial ring load.

APPENDIX

Numerical example of the influence line method of analysis

The spherical steel dome ¼ inch thick and 60 inch radius shown in Fig. 13, is subjected to a radial ring load of 1·60 tons uniformly distributed over a circular path of 5½ inches mean diameter and ¼ inch wide. It is required to determine the distribution of radial deflection, bending and membrane stresses due to the imposed loading. Young's Modulus $E = 13{,}400$ tons/in², Poisson's ratio $v = 0{\cdot}28$. The relevant Reissner constants for this dome are $l = \sqrt{Rt}\Big/\sqrt[4]{12(1 - v^2)}$

$$= \sqrt{60 \times \frac{1}{4}}\Big/\sqrt[4]{12(1 - 0{\cdot}28^2)} = 2{\cdot}125$$

and $\mu = r_p/l = \frac{1}{8}\Big/2{\cdot}125 = 0{\cdot}0588.$

Radial deflections. Consider any point C (Fig. 14) on the surface of the dome.

1. Remove the ring load and apply a unit radial load at C uniformly distributed over a circular area of diameter equal to the ring load path width, in this case ¼ inch. The dome under the action of this unit load only may be regarded as rotationally symmetrical about C and the radial deflection at any radius r measured from C is given by Fig. 3 in non dimensional form. The actual deflection of any point on the ring load path due to the unit load at C may be deduced from Fig. 3, as follows ;—

Consider for example point F (Fig. 14) on the load path. Its radial distance from C $r_3 = 1{\cdot}94$ inches Hence $r/l = 1{\cdot}94/2{\cdot}125 = 0{\cdot}914$. For this value of r/l, $(Et^2/PR)\delta = 0{\cdot}280$ from Fig. 3 as indicated, giving

$$\delta = {\cdot}280 \times \frac{PR}{Et^2} = {\cdot}280 \times \frac{1 \times 60}{13400 \times (\frac{1}{4})^2} = {\cdot}020$$

on substituting the appropriate values of dome dimensions, Young's Modulus and P (the unit load) = 1.

Radial deflections at other points of the load path such as A, D, G etc. are obtained in an exactly similar way. The distribution of these deflections along the ring load path are shown pictorially (for easier visualization) in Fig. 15 and are replotted on the base of the developed length of the ring load path in Fig. 16. As shown in the text, this distribution is in fact the influence line for radial deflection at C, corresponding to a unit load traverse along the load path AB.

2. The total radial deflection at C, due to the ring load along AB, is given by the summation of the products ; load × appropriate ordinate of influence line. In the given case the ring load intensity is a constant $= 1{\cdot}60/\pi \times 5\frac{1}{2} = 0{\cdot}0927$ tons per in. and the total deflection at C becomes $0{\cdot}0927 \times$ Area enclosed by the influence line of Fig. 16. This area may be evaluated numerically or graphically from Fig. 16 and comes to 0·140 in² per ton.

Hence *deflection at* $C = 0{\cdot}0927 \times 0{\cdot}140 = 0{\cdot}013$ in.

The complete distribution of radial deflection along a great circle perpendicular to the ring load path is shown plotted in non-dimensional form in Fig. 5 derived by taking a number of points such as C along the selected great circle and computing the deflections for each as outlined above. It should be noted that in Fig. 5 the radial distance r is measured from the crown of the dome taken as the centre of the ring load circle and P is the total ring load. Correspondingly the coordinate values in Fig. 5 relevant to point C become $(Et^2/PR)\delta = (13{,}400 \times (\frac{1}{4})^2/(1{\cdot}60 \times 60)\ {\cdot}013 = 0{\cdot}113$ and $r/l = 4{\cdot}25/2{\cdot}125 = 2$ as indicated.

Bending and membrane stresses. The basic procedure is exactly the same as for radial deflections, in the stress case however four quantities have to be considered. These are the circumferential and meridional bending and membrane stress actions. Consider again a point such as C (Fig. 14) on the surface of the dome.

1. Removing the ring load and applying the unit load as before again results in a rotationally symmetrical system with respect to C for which the appropriate stress variations are given in non-dimensional form by Fig. 2.

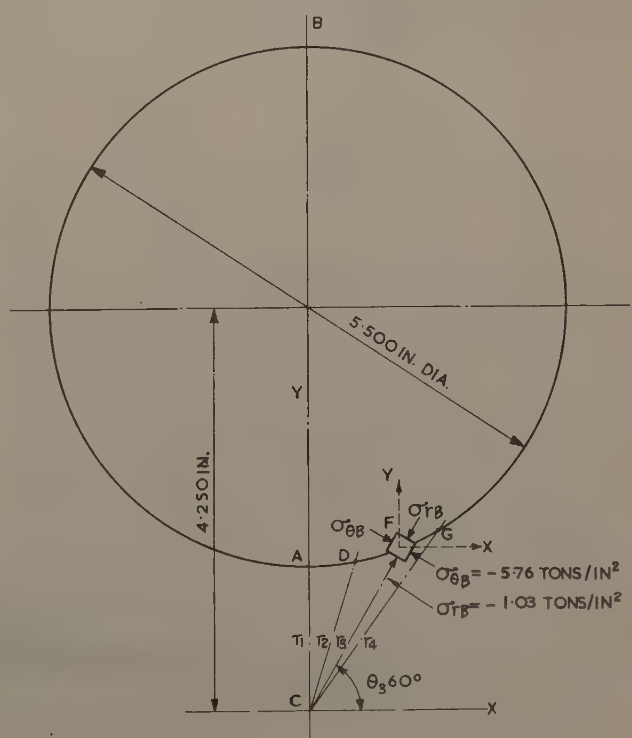


Fig. 14.—Plan view on the loading path AB, showing the bending stresses at F, due to a unit load at C.

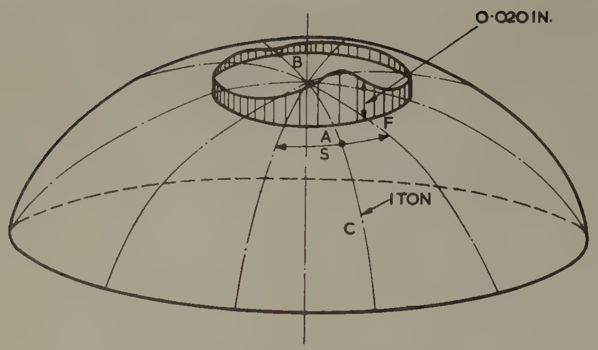


Fig. 15.—Distribution of radial deflection round loading path AB, due to a unit load at C.

Taking as before the point F on the load path as an example, $r/l = 0{\cdot}914$ and the corresponding non-dimensional values of the *bending* stresses are read off from the graphs in Fig. 2 as $\sigma_{\theta B}\, t^2/P = -0{\cdot}360$, and $\sigma_{rB}\, t^2/P = -0{\cdot}064$. Substituting $t = \frac{1}{4}$ in. and $P = 1$, the actual ' unit load ' bending stress values acting at F in Fig. 14 are obtained as $\sigma_{\theta B} = -5{\cdot}76$ and $\sigma_{rB} = -1{\cdot}03$. Noting that these stresses are the circumferential and meridional actions at F with respect to C as the crown of the dome, *their lines of action in plan are perpendicular and parallel to the line* CF as shown in Fig. 14.

The ultimate aim of the unit load analysis is to deduce the circumferential and meridional stresses at C due to the ring load. The lines of actions of these stresses are in the X and Y directions at C and consequently only stress components in these directions are relevant. This implies that the component actions in the X and Y directions of the stresses shown at F in Fig. 14 have to be determined.

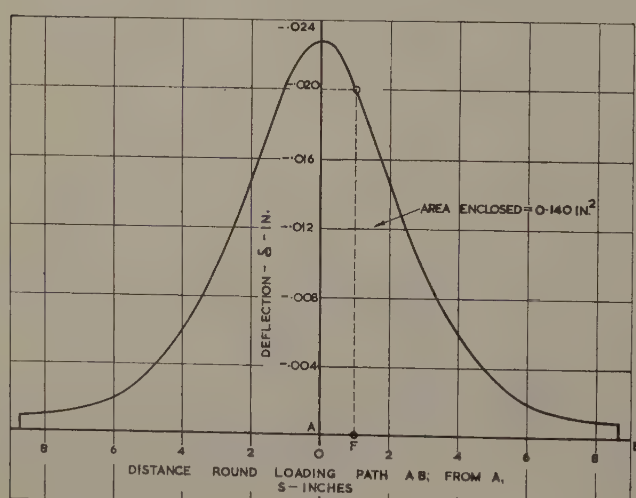


Fig. 16.—Radial deflections round the loading path AB, due to a unit load at C.

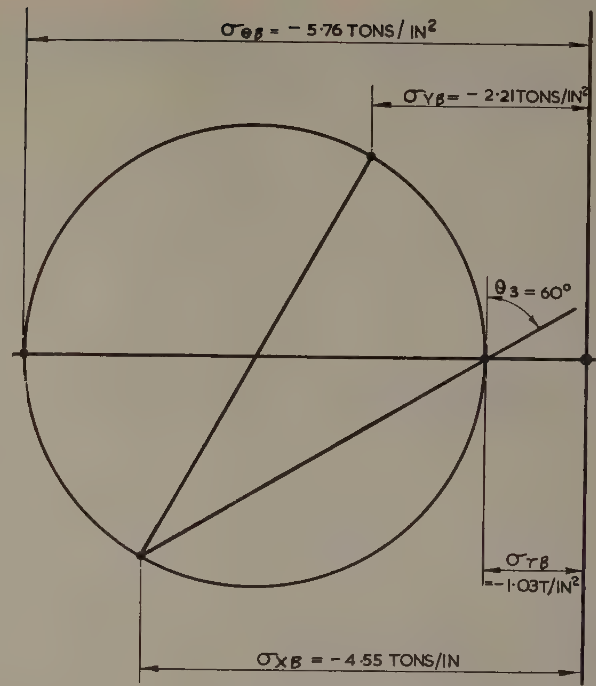


Fig. 17.—Mohr circle resolution for the bending stresses at F.

A very convenient graphical way of doing this, conducive to rapidity of working when dealing with a considerable number of points is the Mohr circle diagram shown in Fig. 17 giving the stress components at F in the X and Y directions respectively as $\sigma_{xB} = -4{\cdot}55$ and $\sigma_{yB} = -2{\cdot}21$. It should be noted that the effects of dome curvature is disregarded

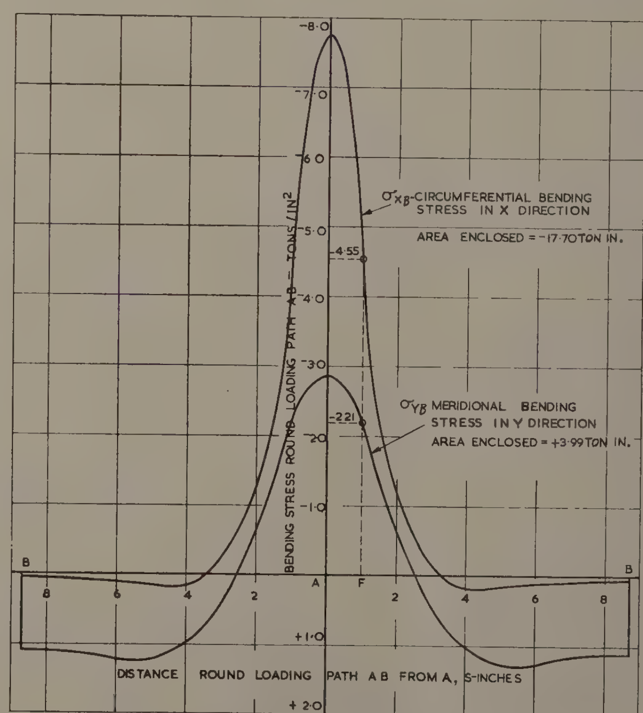


Fig. 18.—Bending stresses round the loading path AB, due to a unit load at C.

Correction. Figs. 16 and 18. The phrases " Area enclosed = 0.140 IN²," " Area enclosed = —17.70 TON IN" and " Area enclosed = +3.99 TON IN," should read " Area enclosed = 0.140," " Area enclosed = — 17.70 " and " Area enclosed = + 3.99 " respectively.

in the stress resolutions as it is generally negligible in comparison with the effects of orientation. Deriving the X and Y components of the bending stresses due to the unit load at C for other points of the load path A, D, G etc. leads as in the case of deflections to the appropriate influence lines for stress at C corresponding to a unit load traverse along the load path AB. These influence lines for the circumferential and meridional bending stresses at C, σ_{xB} and σ_{yB} respectively, are shown plotted on the base of the developed length of the load path AB in Fig. 18. The membrane stress influence lines can be obtained in an exactly similar way.

2. As in the case of deflections the appropriate total values at C due to the ring load are given by ring load intensity $\times$ area enclosed by relevant influence line. Hence circumferential bending stress $\sigma_{\theta B}$ at $C = 0{\cdot}0927 \times$ (area enclosed by σ_{xB} influence line $= -17{\cdot}70) = -1{\cdot}64$ tons/in^2, i. e. compressive on the 'upper' or loaded surface. Meridional bending stress σ_{rB} at $C = 0{\cdot}0927 \times$ (area enclosed by σ_{yB} influence line $= +3{\cdot}99) = +0{\cdot}37$ tons/in^2: i.e. tensile on the 'upper' or loaded surface.

The complete distribution of all stresses along a great circle perpendicular to the ring load path is shown plotted in non-dimensional form in Fig. 4, derived, as in the case of deflections by repeating this procedure for other points such as C along the selected great circle. The co-ordinate values in Fig. 4 relevant to point C with r now referred to the centre of the ring load circle become $r/l = 4{\cdot}25/2{\cdot}125 = 2$,

$$(t^2/P)\sigma_{\theta B} = [(\tfrac{1}{4})^2/1{\cdot}60]\,(-1{\cdot}64) = -0{\cdot}0640$$
$$\text{and } (t^2/P)\sigma_{rB} = [(\tfrac{1}{4})^2/1{\cdot}60]\,(0{\cdot}37) = +0{\cdot}0145$$

and are as shown on the graphs.

Acknowledgments

The use of the influence line concept in the methods of analysis proposed is due to R. M. Kenedi under whose direction A. S. Tooth with the assistance of J. D. W. Hossack carried out the work presented in the paper.

The Authors would like to record their sense of indebtedness to Professor A. S. T. Thomson, Head of the Department of Mechanical, Civil and Chemical Engineering of the Royal College of Science and Technology, Glasgow, for the free use of the Laboratory facilities and to the Motherwell Bridge and Engineering Co. Ltd., Motherwell, for their sponsorship of the research project.

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—Contribution to the discussion by R. M. Kenedi and A. S. Tooth.

Discussion

The Council would be glad to consider the publication of correspondence in connection with the above paper. Communications on this subject intended for publication should be forwarded to reach the Institution by the 30th June 1960.

Book Reviews

Coke-Burning Appliances Handbook, 6th Edition. (London : The Gas Council, Coke Department, 1959). $8\frac{3}{4}$ in. $\times$ $5\frac{3}{4}$ in. 35s.

The new edition of this handbook gives full specifications and details of over four hundred tested and approved solid fuel appliances illustrated by photographs and diagrams. Full technical information on each appliance, including the heat service, is given on data sheets. The book is divided into sections for the various types of appliances, and each section is preceded by introductory notes of technical interest and value. Reference is made at the beginning to the conditions and procedure for approval of appliances, and details on suitable sizing, densities and calorific values of coke are given. The book is in a convenient loose-leaf form to enable additional information to be added.

Architecture U.S.A., by Ian McCullum, A.R.I.B.A. (London : Architectural Press, 1959). $11\frac{1}{2}$ ins. $\times$ $8\frac{1}{2}$ ins., 216 pp., illustr., 63s.

Since 1950 America, a land of achievement, wealth and vitality, has obtained a dominant place in world architecture. It has however remained largely unknown territory for want of a book that sets out to map the whole field of attainment.

Unfortunately we cannot all visit America, and if we can, it is only for a brief visit, when it is impossible in the time available to assess the overall architectural picture.

The aim of the Author has been to bring the architectural scene into clearer focus. The method he has adopted is a survey " in breadth and depth " of the whole field of modern architecture in the United States, by classifying each group of buildings under their respective architects, and giving a brief summary of their careers. As a result of this biographical approach a group portrait is obtained of some of the most stimulating architectural minds in the world today.

The Author's purpose was to present a cross section of the best American architecture today. In this he has succeeded admirably. The wealth of illustrations provided are indeed evidence of the versatility of a nation with a prosperous and lively building industry, creative freedom and vast expenditure of wealth, and an outlook free from prejudice against the new. The book is well presented—if somewhat lacking in plans and sections—and is recommended to structural engineers, architects and students, as a comprehensive survey of virile architectural design in America today.

N.P.K.

The North Western Gas Board's New Coal Carbonising Plant at Garston*

Discussion on the Paper by H. G. Cousins, B.Sc., M.I.Struct.E., M.I.C.E.

Discussion

THE PRESIDENT invited the meeting to accord a vote of thanks to Mr. Cousins for having prepared the paper and for having presented it so admirably. It was a very great pleasure to propose the meeting's thanks to him because, although he had said that he thought the particular building described had not much to recommend it from the structural point of view, Mr. Cousins was being unduly modest in that respect.

At the last meeting of the Institution, as well as at this one, said the President, coloured slides had been used, and he hoped that the use of such slides to illustrate papers would continue.

Mr. C. V. BLUMFIELD (Member) joined in congratulating Mr. Cousins on the work described and expressed his personal appreciation of the paper.

He was very sorry, however, that the structure had become so grimy in the course of time, and said it was a great pity that the owners could not have afforded a little more to keep it clean, because when it was first erected it did indeed look beautiful.

It was very difficult to find anything which Mr. Cousins had left unsaid, but Mr. Blumfield did mention the shell shutters and said he was not quite clear in his mind about them after looking at the photograph of the shuttering unit: he wondered if it were a moving shutter, and invited Mr. Cousins to comment on it.

Mr. COUSINS shared Mr. Blumfield's regret that the building was getting so grimy. He did not know that much could be done about the brickwork, but possibly the aluminium panels could be cleaned down.

Concerning the shutter unit, Mr. Blumfield might have been misled. The little wheels at the bottom of the construction, shown in the picture (Fig. 12), were there for convenience in moving the units about on the ground: they were made on the ground, and it was easier to move them about by means of trollies than to man-handle them. Each one would then be lifted as a complete unit and supported on to ledgers on the side of the main beam. Finally between adjacent sections a make-up piece was added to make a complete shell shutter.

Mr. J. A. DERRINGTON (Associate-Member) commenting on the section of the paper which dealt with the prestressed beams in the front of the building (p. 329), said he gathered that tests were carried out on some of the concrete cubes to try to determine the modulus of elasticity of the material, but these were scrapped and an arbitrary value was adopted for calculations. He did not quite appreciate why this was done.

Asking if Mr. Cousins could give more detail of the stresses in the structure around the beams, he said he would have thought that there had been a great deal of worry about the very high local bending stresses in the columns by reason of movements after stressing the beams. He wondered if Mr. Cousins had taken any readings of column stresses and, if so, how they fitted in with the calculations.

Mr. COUSINS said the point was a very interesting one. First he agreed that the structure was very complex in that there were adjacent beams and columns of large section which would restrain the shortening and bending of the prestressed beam. The proportion of loading from the floors and portals acting on the beam would also be affected by its deflection. It was because of the complexity of the analysis that he had done a little testing and he had measured the strain at various points on the beam to get some idea whether it was behaving as had been assumed in design.

One could measure the strain in this way but that did not give any idea of what the stress was. One would know for instance that the different parts of the beam were under varying compressive stress but not what the actual stress was. To get some idea of the value of E he had tested some cubes by crushing them slowly and plotting the stress strain relation, but the values obtained were obviously wrong. A cube crushing at 4,000 lb/sq. in. indicated a value of E of about $0{\cdot}5 \times 10^6$. He felt that this method of testing was unreliable and that this might be due to the rate of loading. Dr. Rusch at Munich had done a lot of work on this type of test and had shown how the modulus was affected by the type and rate of loading. Having failed to obtain a reliable result from the tests made he had adopted a value of E of 4×10^6 as a reasonable value for the concrete used on the job and translated the strains recorded on the beams into stresses. Using that value the stresses appeared to be in accordance with those calculated and presumably therefore the moments induced in the columns were as had been estimated.

Mr. K. H. BRITTAIN (Associate-Member) asked if a layer of any material had been placed between the cube and platen of the machine when the modulus of elasticity determination was attempted. The restraint on the cube surface was one of the factors which prevented the modulus being determined satisfactorily in that way, and the normal method was to have a longer specimen and to measure the strain on the centre portion.

*Read before the Institution of Structural Engineers at 11, Upper Belgrave Street, London, S.W.1., on the 12th November 1959. Mr. L. E. Kent B.Sc., M.I.Struct.E., M.I.C.E. (President) in the Chair. Published in "The Structural Engineer" Vol. XXXVII, No. II, pp. 322-334. (Nov. 1959).

Mr. COUSINS confessed that he was not very well versed in the intricacies of testing. He agreed that a cube was a small thing: probably one needed a much larger specimen to get a satisfactory result. Certainly we could do with an easier method of testing for E: maybe someone had sorted this out by now.

Mr. DERRINGTON said that the British Standard Specification No. 1881 on "Methods of Testing Concrete" gave a standard method of assessing the Young's modulus for concrete.

Mr. BRITTAIN added that a dynamic modulus was obtained by the ultrasonic pulse measurement technique.

Mr. T. A. SMITH, who was engaged on the job at Garston for 2½ years as a contractor's agent, said it had taken quite a long time to carry out, largely because Mr. Cousins, as the structural designer, was in the hands of a multitude of people who were at the same time trying to design plant: due to this concurrent progress of design, quite often Mr. Cousins was held up for lack of the basic information by means of which he could carry on with the structural design. During the course of the job one had often wondered how he had managed to design it at all: and he had not taken any credit for that. Anyone who was familiar with the process of design would realise just how much extra work was involved in what was basically a very complex structure.

One case which came to Mr. Smith's mind was the gable end of No. 1 retort house, intersected with the floors of the turbine room and for the waste heat boilers. When Mr. Cousins was designing the No. 1 retort house he was not getting enough information with which to design the frame to support the gable, and this difficulty had to be overcome in order to allow the work on the retort house to proceed, while waiting for that information. It was in fact overcome by building the two end shells, without a gable frame to support them. They were built on two parallel sets of independent scaffolds, and the edge beam for each end shell, Nos. 1 and 5, was cast on trestles. The roof, composed of five shells, was completed before one of the gables was started.

That was one of the problems which the contractors had to solve, and it was a most odd way of erecting a building, rather a Chinese way, starting at the top and working downwards. A lot of these problems had arisen for the contractors, but he was quite sure that Mr. Cousins had many more, which had made a very fine design much more difficult of execution than it need have been. Mr. Cousins had not drawn attention to that in his paper: but one felt that, when judging the value of the design, it was a big factor of which everybody should be aware.

Mr. COUSINS thanked Mr. Smith for his remarks and agreed that they were faced with quite a number of problems in designing the building as it went up, putting the cart before the horse.

That seemed a slow way of erecting a building: had all the drawings been ready in the first place they could have erected it very much more quickly. On the other hand, time was in fact saved, taking the plant as a whole. For instance, in the case of No. 2 retort house, the retort settings and other plants could be constructed before the building structure. The No. 1 retort house structure was put up before the retort settings were built. Although the structure was big, it was a very small factor in relation to the whole of the work that was done, and in fact the Gas Board began to make gas at those works sooner than would have been the case if they had settled down and worked out all the detail and then had smacked the buildings up in spectacular style.

In acknowledging how much he appreciated the work that was done by Mr. Smith, who was representing Taylor Woodrow Constructions, Ltd., Mr. Cousins said he had admiration for the way in which the Contractors had erected the building and had tackled the various problems which they had had to face in connection with it.

Mr. B. L. CLARK (Member) said that it would seem from the bending moment diagram relating to the cross section, that there would be deflection of the framework at roof level. That would mean the whole roof would deflect horizontally, but as the roof was a large concrete diaphragm or beam of considerable depth, the whole of the horizontal transverse loading would be taken back on to the gable frames which appeared from the drawings and slides to be extremely stiff.

In his opinion it was not possible for a concrete roof, which was only twice the span in length, or thereabouts, to deflect in the manner of a beam sufficiently to absorb the displacement indicated by bending moments in transverse frames in which the columns were unrestrained at their top.

Mr. COUSINS, after thanking Mr. Clark for his remarks, agreed that there was a sway on the structure, and that put a bending moment into the roof as a horizontal beam. An examination was made of the deflection and of the amount of wind loading that could be carried on the gable end. In the paper he had stated (p. 327) that; "Consideration of the relative deflections of the cross frames and of the end walls showed that approximately 30 per cent of the wind load would be carried by the roofs to the end walls. . . ." So that the diagram of bending moments (Fig. 4) would really represent about 70 per cent of what it would be if there were no end frame and end gable to stiffen it.

Mr. J. HINTON (Associate-Member) asked if he were right in thinking that the column shutters were carried past the beams, leaving holes for fixing beams. If the lifts of concreting were restricted to about 8 feet, which was normal, he asked what advantages there were in this method, which he had not met before. He thought difficulties might arise in fixing reinforcement, and in properly consolidating concrete below boxes formed in the column shuttering.

Mr. COUSINS speaking from memory said that 8 ft. was about the maximum lift on the columns at one time. The idea of the holes came from Mr. Smith. The contractors wanted to avoid having to fit column shutters round beams which were at rather awkward centres and had complicated shapes. They were able to avoid cutting the column shutters by using the box which could be knocked out after the column shutters were struck, leaving a hole through the column through which the beam reinforcement and concrete could be placed. This method could be used if the size of the beam were not too great compared with the size of the column. It was necessary to have enough column section left on either side of the beam to get the concrete past the beam box. In this particular case there were thin but fairly wide columns through which the beams could fit easily.

Mr. HINTON said he was wondering how to get the column concrete past the box.

Mr. COUSINS replied that this was a question of satisfactory site compaction and he must give tribute to the contractors for the way in which they had done this.

Mr. SMITH, supplementing Mr. Cousins' remarks on this matter, said the main columns, which were 4 ft. plus by 1 ft., had holes through them. At Garston the concreting from the retort bench level to the under side of the shell was done in about 12 lifts, and only the one pair of shutters was used. The beams intersecting with the main columns were of odd shapes and varied in cross-section throughout the building.

Mr. CLARK asked what finishing treatment was applied to the aluminium panels, and what expectation of life would these have at a gas works?

Mr. IAN MACLAREN (Architect for the structure at Garston) replied that they had met some difficulty with the stove enamelled aluminium there because it had changed colour, and the suppliers stated they had never met that situation before: there was a gold sheen over the entire front, which, oddly enough, looked rather nice. However, chemical tests were being applied in trying to find why that had occurred.

Mr. DERRINGTON (Associate-Member), having been concerned with some work on a gasworks, asked if anything was done to make the concrete more resistant to chemical attack.

Mr. COUSINS replied that that was considered. They had made tests on the soil and had obtained a shocking result where chemicals had previously been tipped: there was nothing which would resist what had been found and they had removed that soil which had been contaminated. Elsewhere the soil was such as to give no likelihood of attack. The use of sulphate resisting cement had also been considered for the structure above ground level but the risk of attack was not considered sufficient to justify the additional cost of this cement.

THE PRESIDENT referred to the use of ready-mixed concrete, and pointed to the statement (p. 332) that a mobile endless conveyer belt was used to elevate this concrete from ground level outside the building to the top level of the blocks, from whence it was distributed throughout each block by a series of chutes, each block being cast in one pour. He wondered what it looked like by the time it got to the end of its journey, because his experience was that one should get it to the site and put it in its final position as soon as possible.

Mr. COUSINS said that, as stated in the paper, the alternator blocks could not be cast until after the boilers had been lifted into position 60 feet overhead. The alternator foundations were in the basement, and in removing the ready-mixed concrete from the lorry, which arrived within 20 feet of the alternator blocks, they had to elevate it only 4 or 5 feet. There was really no time lost in the delivery of the concrete to the alternator blocks. The blocks had turned out in a most remarkable fashion: they looked like marble.

THE PRESIDENT said he must have been misled by the reference to elevating the concrete "to the top level of the blocks."

He then expressed the thanks of the meeting to Mr. Cousins for the way in which he had answered the questions.

Written Discussion

Mr. R. M. AMODIA (Graduate) asked for information on the following points referred to in the paper;

(a) he would appreciate it if the Author could supply a sketch showing the standard detail of steam pipe and anchorage (p. 328)

(b) what were the advantages of glass-fibre tank and motor-driven measuring valve for quenching water? (p. 329)

(c) referring to the blasting operations, the Author stated that special care had been exercised due to overhead gas mains. Could he outline the nature of these precautions? (p. 331)

(d) with regard to the shell-roof shuttering, what was the spacing of the twin 8 in. × 2 in. timber bearer?

(e) in connection with the track foundation for tower crane it was stated in the paper (on page 333) that "no load was transmitted to the 36 inch diameter gas main situated under one of the rails at an average depth of 6 feet." How exactly was this achieved?

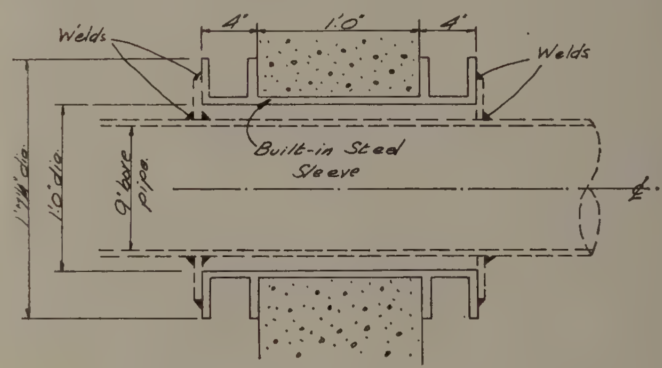

Fig. A

THE AUTHOR replied as follows;

(a) Fig. A illustrated the type of anchorage used for the steam pipe.

(b) the advantage of glass-fibre tanks was firstly, cost and secondly, lack of maintenance, and the use of a motor driven valve ensured a fully automatic and accurate quantity of quenching water.

(c) the precautions taken in blasting were to limit the charge and to cover the explosion so that flying missiles could not damage the main.

(d) the bearers for the shell roof supports were spaced at about 2 ft. centres.

(e) the sleepers supporting the rails were carried over on to concrete pads on either side of the gas main, the earth being kept down below the sleepers directly over the main.

Institution Notices and Proceedings

ORDINARY GENERAL MEETING

An Ordinary General Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1., on Thursday, 25th February, 1960, at 5.55 p.m. Mr. Lewis E. Kent, B.Sc., M.I.Struct.E., M.I.C.E. (President), in the Chair.

The following members were elected in accordance with the Bye-Laws. Will members kindly note that the elections, as tabulated below, should be referred to when consulting the Year Book for evidence of membership.

Students

Bangah, Gurkishen Kumar, of Malacca, Federation of Malaya.
Beacham, David Gordon, of Bristol.
Chia Cher Keng, of Singapore.
Clark, Michael Anthony, of Worthing, Sussex.
Foster, Sala Robert, of Bulawayo, Southern Rhodesia.
Fox, Howard Edwin, of Lambley, Nottingham.
Fuller, Norman, of Manchester.
Gregory, Henry Catchick, of London.
Grobbelaar, Charl, of Johannesburg, South Africa.
Hamblin, Anthony Raymond, of Holcombe, nr. Bath, Somerset.
Jacobs, Dawid Johannes, of Pretoria, South Africa.
Lim Choong Kong, of Sungei Siput, (N) Perak, Malaya.
Lim Yong Keat, of Ipoh, Perak, Malaya.
Macfarlane, James Marshall, of Glasgow.
Potgieter, Theodorus Daniel, of Vandyksdrif, Transvaal, South Africa.
Sivaganabalan, S/O Thambirajah, of Petaling Jaya, Selangor, Malaya.
Taiwo, Aremu Olalekan, of London.
Tay, William Joseph, of Singapore.
Young, Allan Malcolm, of Salisbury, Southern Rhodesia.

Graduates

Bell, Thomas John, of Airdrie, Lanarkshire.
Bottomley, Kenneth, of Billingham, Co. Durham.
Brooke, John Philip, of London.
Caldwell, Aubrey Keith, of Durban, Natal, South Africa.
Chambers, Peter Thomas, of Birmingham.
Dandy, John, of Tyldesley, nr. Manchester.
Devonport, Derek Kenneth, of Birmingham.
Dorman, William Wright, of Glasgow.
Frederick, Alan Henry, of Toronto, Ontario.
Hill, Derek Richard Rowland, of Worthing, Sussex.
Kanoo, Adbul Latif, of London.
Kay, William, of Salford, Lancashire.
Keeton, Michael Fenwick, of Sheffield.
McFarlane, John, of Horley, Surrey.
Narasimha Murthy, Samudrala, B.E., of Jaggayyapet P.O., Andhra Pradesh, India.
Perks, David Roy, of Birmingham.
Proctor, George Mordue, of Ottawa, Ontario, Canada.
Puranik, Arvind Narhar, B.Eng., of Poona, India.
Rangachari, Jaganathan, B.E., of Madras, South India.
Reid, Thomas Wylie, of Paisley, Renfrewshire.
Smith, Michael Ford, of Radcliffe-on-Trent, Nottinghamshire.
Strachan, Charles Douglas, B.Sc., of Dundee.
Sultan, Gultekin, of Bolton, Lancashire.
Summerfield, Frank, B.Sc.Tech., of Stockport, Cheshire.
Tamhankar, Mohan Gopal, B.E., of Bombay, India.
Temblett, John, of Keynsham, Somerset.
Torpey, Brian Desmond, of Dublin, Ireland.
Wellman, Robert James, of Salisbury, Wiltshire.
Wilkinson, Kenneth Ralph, of Tunbridge Wells, Kent.

Associate-Members

Bulson, Philip Stanley, B.Sc., Ph.D., A.M.I.Mech.E., of Lymington, Hampshire.
Kanetkar, Waman Shiuram, B.Eng., of Bombay, India.
Purdy, Frederick, of London.

Transfers

Students to Graduates

Bradford, Neville Edwin, of Durban, Natal, South Africa.
Cox, Gordon Frank, of Bristol.
Gibson, Thomas Keith, of Manchester.
Humphrey, Arthur Thomas, of Chelmsford, Essex.
Jackson, Peter, B.Sc., of Leicester.

Graduates to Associate-Members

Geddes, Brian Sydney, of Manchester
Harkness, Brian Armstrong, B.A.I., of Belfast, Northern Ireland.
Lambert, Michael Francis, of Bolton, Lancashire.
Patel, Jayant, of Nairobi, Kenya.
Patel, Naginbhai Fakirbhai, B.E., of Uganda.
Rimmer, William, of Winwick, nr. Warrington, Lancashire.
Sen, Tarunendra, of London.

Associate-Members to Members

Albery, Allan Crofton Rolleston, M.C., B.A., M.I.C.E., of Toronto, Canada.
Ashraf, Mohammed, B.Sc., of Lahore, W. Pakistan.
Coppen, Frank, of Guildford, Surrey.
Cousins, Robert Henry, B.Sc., M.I.C.E., of Frodsham, via Warrington, Cheshire.
Gedye, Noel Trevor, of Bluff, Southland, New Zealand.
Loadsman, Roy Vernon Charles, of London.
Smith, John Edwin, of Johannesburg, South Africa.

Members to Retired-Members

Bottomley, John Hubert, of Lancaster.
Mears, Robert Peel, B.A.(Cantab.), M.I.C.E., of Godalming, Surrey.
Nixon, Joseph, A.M.I.Mech.E., of Southport, Lancashire.
Pastakia, Shiawax Cowasji, A.R.I.B.A., of Bombay, India.
Pasterfield, Vere Clarence, F.R.I.C.S., of London.
Squire, Rupert Henry, of Burton Joyce, Nottinghamshire.
Taylor, Richard, of Norwich.

Associate to Retired Associate

Field, Leonard Martin, L.R.I.B.A., A.R.I.C.S., of Gosport, Hampshire.

Associate-Members to Retired Associate-Members

Allaway, Ernest George, of Stockton-on-Tees, Co. Durham.
Brown, John Conrad, M.B.E., A.M.I.Mech.E., of Douglas, Isle of Man.
Davies, Frank, of Blackpool, Lancashire.
Thomas, Harold Evan, M.C., of Maidstone, Kent.
Webster, Arthur Francis, A.M.I.C.E., of Ashford, Kent.

OBITUARY

The Council regret to announce the deaths of Major Thomas Schofield Darbyshire, Charles Alfred Harding (Members); Thomas Carlyle Grisenthwaite, Arthur Watson Legat, Thomas Babington Macaulay, Reuben Swager (Retired Members); William Arthur Whitwell (Associate); Herbert Leslie Smith (Associate-Member).

RESIGNATIONS

Notification was given that the Council had accepted with regret the resignations of Percy George Bowie, Myles Honohan Resuggan Cogan, Archibald Kent Leitch (Members); Lt. Col. Charles Herbert Gibson, Henry Malcolm Harding (Retired Members); Leslie Foster, Hugh Alexander Fullarton, Frank Hoyle (Associate-Members); Douglas Osborne Baker, Bryan John Bedford, Michael Yue Onn Fam, Herbert William Gee, Derek John Mariner Morling, Edwin Norbert Morris, John Didsbury Moss, Raymond Sutcliffe, Brian Colin Walker, Dudley Spencer Wills (Graduates).

ADDITIONAL MEETING

Thursday, 7th April, 1960

An additional Ordinary Meeting of the Institution will be held at 11, Upper Belgrave Street, London, S.W.1, on Thursday, 7th April, 1960, ac 6 p.m., when Lt.-Colonel G. W. Kirkland, M.B.E.(Mil.), M.I.Struct.E., M.I.C.E. (Vice-President), will give a paper entitled "Tall Buildings—Problems in the design and construction as affecting the structural engineer."

FORTHCOMING MEETINGS

The following meetings will be held at 11, Upper Belgrave Street, London, S.W.1.

Thursday, April 28th, 1960

An Ordinary General Meeting for the election of members will be held on Thursday, 28th April, 1960, at 5 p.m.

Thursday, May 26th, 1960

Ordinary General Meeting for the election of members at 5.55 p.m., followed by the Annual General Meeting at 6 p.m.

Thursday, June 23rd, 1960

Ordinary General Meeting for the election of members at 5 p.m.

Members wishing to bring guests to the Ordinary Meeting announced above are requested to apply to the Secretary for tickets of admission.

EXAMINATIONS, JULY, 1960

The Examinations of the Institution will next be held in the United Kingdom and overseas on Tuesday and Wednesday, July 12th and 13th, 1960 (Graduateship) and Thursday and Friday, July 14th and 15th, 1960 (Associate-Membership).

REPRESENTATION

The Council have appointed the following Institution representatives:

Code of Practice for Buildings, Protection of Buildings against Water from the Ground BLCP/22

Mr. Donovan H. Lee (Member of Council) (re-appointment)

Mr. A. P. Mason (Member) (re-appointment)

Dimensions of Standard Cold Formed Steel Sections, B.S.I. Technical Committee LSE/59

Mr. R. C. Buxton (Associate-Member) (re-appointment)

British National Committee for Non-Destructive Testing

Professor S. R. Sparkes (Member of Council) (re-appointment)

Professional Classes Aid Council

Mr. F. S. Snow, C.B.E. (Past President) (re-appointment)

Southern Regional Council for Further Education—Advisory Committee for Building

Mr. S. C. Gibbins (Retired Associate) (re-appointment)

Ministry of Education Joint Committee for National Diplomas and Certificates in Building

Mr. K. Severn (Member of Council)

Mortar Tests, B.S.I. Technical Committee CEB/14

Mr. W. Hunter Rose (Member)

Metal Scaffolding, B.S.I. Technical Committee, PEB/1

Professor W. Merchant (Member of Council)

Mr. G. B. Godfrey (Associate-Member of Council)

OVERSEAS REPRESENTATIVE

The Council have appointed Mr. D. MacGregor (Associate-Member) Institution representative in New Zealand (North Island) in place of Professor S. Irwin Crookes, who is retiring.

FIFTIETH ANNIVERSARY CONFERENCE

A report of the Conference on the general theme of "The Future of Structural Engineering" which was held at the Institution's headquarters from the 7th to the 10th October, 1958, as part of the Jubilee celebrations, has been published in one volume under the title, "Proceedings of the Fiftieth Anniversary Conference, 1958." Copies may be obtained from the Institution, price £5 plus two shillings postage.

INSTITUTION REPORTS

The following Institution Reports have been withdrawn:

24/1941, Report on Buildings damaged by Air Raids and Notes relative to Reconstruction. (This is now obsolete).

32/1951, First Report on Prestressed Concrete. (This is superseded by CP 115, "The Structural Use of Prestressed Concrete in Buildings.").

EXAMINATION PRIZE AWARDS

As announced in the March issue of the Journal, the Examinations of the Institution under the new syllabuses will take place in July, 1961. In view of the revision of the syllabuses, the terms of the Prize Awards in connection with the examinations have also been revised and, as from July, 1961, will be as follows:

Andrews Prize

The Andrews Prize will be awarded to the candidate who obtains the highest aggregate of marks in Section A of the Associate-Membership Examination, passing in both subjects.

Wallace Premium (Senior)

The Wallace Premium (Senior) will be awarded to the candidate who passes the whole of Section A of the Associate-Membership Examination and obtains the highest marks in the paper, "Theory of Structures."

Husband Prize

The Husband Prize will be awarded to the candidate who, having passed at one attempt in both subjects in Section A of the Associate-Membership examinatior obtains the highest marks in Section B.

A. E. Wynn Prize

The A. E. Wynn Prize will be awarded to the candidate who obtains the highest marks in Section B of the Associate-Membership examination, provided that he submits a reinforced concrete design.

Graham Wood Prize

The Graham Wood Prize will be awarded to the candidate who obtains the highest marks in Section B of the Associate-Membership examination, provided that he submits a structural steelwork design.

Wallace Premium (Junior)

The Wallace Premium (Junior) will be awarded to the most successful candidate in the Graduateship examination, passing in all subjects (as at present under the current regulations).

NOTICE TO MEMBERS

The attention of members is drawn to the fact that certain former members whose names have been removed from the Register of the Institution have continued to use the official initials designating themselves as members in contravention of the Bye-Laws of the Institution, together with certain other persons, and have held themselves out as members of the Institution although not entitled to do so.

In the past the Council have deemed it sufficient to accept an undertaking in writing from such former members and others not to transgress in the future, but inasmuch as further cases are still reported, the Council have decided that in future legal proceedings will be instituted and an injunction and damages sought to restrain any such persons from offending in such manner.

In order to maintain the high reputation and prestige of the Institution members are asked to assist the Council and to report to the Council any cases which may come to their notice of former members or others wrongfully holding themselves out as members of the Institution whether by the use of initials or otherwise.

EXAMINATIONS

PREPARATION FOR THE EXAMINATIONS OF THE INSTITUTION BY ATTENDANCE AT TECHNICAL COLLEGES

A candidate for Graduateship or Associate-Membership may be able to attend a Technical College; these notes are intended to guide him in choosing the most suitable instruction.

PREPARATION FOR THE GRADUATESHIP EXAMINATION

Technical Colleges offer :

(a) Full-time courses for degrees or Higher National Diplomas in Building or Engineering.

(b) Part-time day or evening courses for Higher National Certificates in Building or Engineering.

If he obtains a Higher National Certificate or Diploma complying with Appendix 11, Section V, of the Regulations Governing Admission to Membership, the candidate will be exempted from the Graduateship Examination.

Alternatively, he may study subjects selected from the available courses and sit the Graduateship Examination. At Technical Colleges, courses are usually available in Building Science or Engineering Science, Strength of Materials, Theory of Structures and Surveying, but students are not normally allowed to select subjects from National Diploma or Certificate courses unless they can show evidence of sound training in more elementary studies. The advice of the College Authorities should be followed.

PREPARATION FOR THE ASSOCIATE-MEMBERSHIP EXAMINATION

At some Technical Colleges there are part-time courses in Structural Engineering which cover the syllabus of the Associate-Membership Examination. At other colleges the candidate must rely on Higher National Certificate courses or on advanced courses in Building, Civil Engineering or Municipal Engineering. These cover only part of the requirements for the Associate-Membership Examination.

Colleges in List " A " provide at least two years of instruction in Theory of Structures and in Structural Engineering Design and Drawing up to Associate-Membership standard. They also give instruction in Structural Specifications, Quantities and Estimates.

List " A "

- Bath Technical College.
- Belfast College of Technology.
- Birmingham College of Advanced Technology.
- Bolton Technical College.
- Bradford Institute of Technology.
- Bridgend Technical College.
- Bristol College of Technology.
- Chesterfield College of Technology.
- Coatbridge Technical College, Lanarkshire.
- Derby and District College of Technology.
- Dudley and Staffordshire Technical College.
- Glasgow Royal College of Science and Technology.
- City of Liverpool College of Building.
- L.C.C. Brixton School of Building, S.W.4.
- L.C.C. Hammersmith College of Art and Building.
- Manchester College of Technology.
- Middlesbrough, Constantine Technical College.
- Nottingham and District Technical College.
- Portsmouth College of Technology.
- Salford, Royal Technical College.
- S.E. London Technical College, Worseley Bridge Road, S.E.26.
- S.W. Essex Technical College, Walthamstow, E.17.
- Southampton Technical College.
- Stafford County Technical College.
- Stockport College of Further Education.
- Twickenham Technical College.
- Willesden Technical College, N.W.10.

Colleges in List " B " provide instruction in Theory of Structures from which the student may reach Associate-Membership standard, but instruction in Structural Engineering Design and Drawing and in Structural Specification, Quantities and Estimates, is not usually so complete.

List " B "

- Brighton Technical College.
- Cardiff Technical College.
- Edinburgh, Heriot-Watt College.
- Huddersfield Technical College.
- Leeds College of Technology.
- London, Battersea College of Technology, S.W.11.
- London, Northampton College of Advanced Technology, E.C.1.
- L.C.C. Westminster Technical College, S.W.1.
- Newcastle upon Tyne, Rutherford College of Technology.
- Plymouth and Devonport Technical College.
- Preston Harris Institute.
- Rotherham College of Technology.
- S.E. Essex Technical College, Dagenham.
- Wigan Mining and Technical College.
- Woolwich Polytechnic, S.E.18.
- West Ham College of Technology.

Students are advised to take the organised courses in Structural Engineering where these are available.

FAIR COPYING DECLARATION

The Institution of Structural Engineers, in common with other scientific and learned societies, subscribes to the Royal Society's Fair Copying Declaration, which reads as follows :

For some time scientists have discussed the problems, created by the Copyright Act, which arise when they wish to obtain reproductions of excerpts from scientific and technical periodical publications. In the normal course of their work, scientists occasionally require for frequent reference, copies of particular papers appearing in scientific periodicals which are not readily available to them. It is assumed that they take all reasonable steps to secure the original journals or separates of papers they require, either from the author or the publisher, but it is recognised that many requirements cannot be met from these sources. We have, therefore, agreed to make the following declaration to ensure that scientists have no undue difficulties in obtaining copies from libraries and other organizations supplying information. This declaration does not apply to books and other non-periodic or non-serial publications.

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Branch Notices

LANCASHIRE AND CHESHIRE BRANCH

The following meeting has been arranged :

Thursday, 7th April, 1960

Annual General Meeting.

At the College of Science and Technology, Manchester commencing 6.30 p.m. Light refreshments will be available from 5.45 p.m.

MERSEYSIDE PANEL

The following meetings have been arranged :

Wednesday, 6th April, 1960

Joint Meeting with the Liverpool Architectural Society.

Mr. Howard V. Lobb, C.B.E., F.R.I.B.A., on "Nuclear Power Stations."

At Bluecoat Chambers, School Lane, Liverpool, commencing at 6 p.m.

Monday, 25th April, 1960

Annual General Meeting of the Merseyside Panel.

At the Liverpool Engineering Society, The Temple, Dale Street, Liverpool, at 6.30 p.m., preceded by light refreshments from 5.30 p m.

Friday, 6th May, 1960

Annual Dinner Dance.

At the Carlton Club, Eberle Street, Liverpool.

Hon. Secretary : W. S. Watts, A.M.I.Struct.E., A.M.I.C.E., 11, Newchurch Lane, Culcheth, nr. Warrington, Lancs.

MIDLAND COUNTIES BRANCH

The following meetings have been arranged :

Friday, 22nd April, 1960

Annual General Meeting, followed by a lecture details of which will be announced.

At the James Watt Memorial Institute, Great Charles Street, Birmingham, at 6.30 p.m. Tea will be served from 5.45 p.m.

Hon. Secretary : S. M. Cooper, A.M.I.Struct.E., "Applegarth," Hyperion Road, Stourton, nr. Stourbridge, Worcestershire.

GRADUATES' AND STUDENTS' SECTION

The following meetings have been arranged :

Friday, 1st April, 1960

Mr. A. T. Clarke, M.I.Struct.E., Branch Chairman, on "Some Experiences and Faults in Reinforced and Prestressed Concrete."

Followed by the 13th Annual General Meeting.

At the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, commencing 6.30 p.m., preceded by tea from 6 p.m.

Friday, 6th May, 1960

Third Annual Buffet Dance, at the Station Hotel, Dudley.

Hon. Secretary : H. T. Dodd, Shepherd's Cottage, Grove Lane, Wishaw, Sutton Coldfield, Warwickshire.

NORTHERN COUNTIES BRANCH

The following meetings have been arranged :

Tuesday, 5th April, 1960

At Middlesbrough. Mr. Frederick S. Snow, C.B.E., M.I.Struct.E., M.I.C.E., M.I.Mech.E. (Past President) and E. V. Finn, A.M.I.Struct.E., A.M.I.C.E., on "The Structural Engineering Aspects of the Development of Gatwick Airport."

At the Cleveland Scientific and Technical Institution, commencing 6.30 p.m., preceded by buffet tea at 6 p.m.

Wednesday, 6th April, 1960

At Newcastle. Annual General Meeting, after which the above paper will be repeated.

At the Neville Hall, commencing 6.30 p.m., preceded by buffet tea at 6 p.m.

Friday, 22nd April, 1960

Annual Dinner. At the Corporation Hotel, Middlesbrough.

Hon. Secretary : P. D. Newton, B.Sc., A.M.I.Struct.E., A.M.I.C.E., c/o Richard Hill Ltd., P.O. Box 29, Middlesbrough, Yorkshire.

NORTHERN IRELAND BRANCH

The following meeting has been arranged :

Tuesday, 5th April, 1960

Annual General Meeting and Film Evening.

At the Civil Engineering Department of the Queen's University of Belfast at 6.30 p.m., preceded by tea at 5.45 p.m.

Hon. Secretary: L. Clements, A.M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E., 3, Kingswood Park, Cherryvalley, Belfast.

SCOTTISH BRANCH

The following meeting has been arranged :

Tuesday, 19th April, 1960

Annual General Meeting.

At the Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, commencing 7 p.m.

Hon. Secretary: W. Shearer Smith, M.I.Struct.E., A.M.I.C.E., c/o The Royal College of Science and Technology, George Street, Glasgow, C.1.

SOUTH WESTERN SECTION

Hon. Secretary: C. J. Woodrow, J.P., "Elstow," Hartley Park Villas, Mannamead, Plymouth, Devon.

WALES AND MONMOUTHSHIRE BRANCH

The following meetings have been arranged :

Friday, 8th April, 1960

Annual Dinner. At Swansea.

Wednesday, 4th May, 1960

Annual General Meeting. At Swansea.

Meetings will be held at the Mackworth Hotel, High Street, commencing 6.30 p.m.

Hon. Secretary: K. J. Stewart, M.I.Struct.E., A.M.I.C.E., 15, Glanmor Road, Swansea.

WESTERN COUNTIES BRANCH

The following meeting has been arranged :

Friday, 1st April, 1960

Annual General Meeting 6 p.m., followed at 7 p.m., by a paper to be given by Mr. John Mason, B.A. (Cantab.), M.I.Struct.E., A.M.I.C.E. (Hon. Treasurer) entitled "A Commentary on the New British Standard 449 (1959). The Use of Structural Steel in Building."

At the Small Lecture Theatre, University Engineering Laboratories, University Walk, Bristol 8, commencing 6 p.m., preceded by tea at 5.30 p.m.

Hon. Secretary: A. C. Hughes, M.Eng., A.M.I.Struct.E., A.M.I.C.E., 21, Great Brockeridge, Bristol 9.

YORKSHIRE BRANCH

The following meetings have been arranged :

Friday, 1st April, 1960

At York. Annual Dinner and Dance. At the Royal Station Hotel, 7 p.m.

Wednesday, 6th April, 1960

At Sheffield. Mr. H. J. Purkis, B.A., B.Sc., on "The Present Position of Sound Insulation in Buildings."

At the Royal Victoria Hotel, commencing 6.30 p.m., preceded by buffet tea at 6.15 p.m.

Wednesday, 20th April, 1960

At Leeds. Annual General Meeting, followed by a paper given by Mr. E. J. Martin, M.I.Struct.E., entitled "Reinforced Concrete Construction for a new Limestone Quarrying and Treatment Plant."

At the Metropole Hotel, King Street, commencing 6.30 p.m., preceded by buffet tea at 6.15 p.m.

Hon. Secretary: W. B. Stock, A.M.I.Struct.E., 34, Hobart Road, Dewsbury, Yorks.

UNION OF SOUTH AFRICA BRANCH

Hon. Secretary: A. E. Tait, B.Sc., A.M.I.Struct.E., A.M.I.C.E., P.O. Box 3306, Johannesburg, South Africa.

During weekdays Mr. Tait can be contacted in the City Engineer's Department, Town Hall, Johannesburg. Phone 34-1111, Ext. 257.

Natal Section Hon. Secretary: J. C. Panton, A.M.I.Struct.E., A.M.I.C.E., c/o Dorman Long (Africa) Ltd., P.O. Box 932, Durban.

Cape Section Hon. Secretary: R. F. Norris, A.M.I.Struct.E., African Guarantee Building, 8, St. George's Street, Cape Town.

EAST AFRICAN SECTION

Chairman: R. A. Sutcliffe, M.I.Struct.E.

Hon. Secretary: K. C. Davey, A.M.I.Struct.E., P.O. Box 30079, Nairobi, Kenya.

NIGERIAN SECTION

Chairman: J. W. Henderson, E.R.D., B.Sc., M.I.Struct.E., M.I.C.E.

Hon. Secretary: A. Brimer, A.M.I.Struct.E., Brimer, Andrews & Nachshen, Private Bag Mail 2295, Lagos, Nigeria.

SINGAPORE AND FEDERATION OF MALAYA SECTION

Chairman: T. F. Lee, B.Sc.

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"*Construction of Four Spinning Sheds at Mehalla El Kobra, Egypt*" by G. E. Mahfouz (Associate Member).
"*Strengthening of Kalimachak Bridge—5 × 100 ft. span*" by K. K. Rao (Associate Member).
"*Strengthening of Large Concrete Gravity Dams*" by G. S. Boris (Member).

Book Reviews

Baustatik, Theorie und Beispiele, by Kurt Hirschfeld. (Berlin : Springer-Verlag, 1959). 823 pp., DM 76.50

This book of over 800 pages is written in German and although much of the mathematical work can be understood through the numerous diagrams, it would still be well to have a knowledge of German to obtain full value from the reading of this work. There are six major chapters followed by a chapter of examples, and a chapter which consists of a number of tables giving data and solutions for a large variety of types of structural forms. Starting with the study of the degree of redundancy of structures, this massive volume continues with methods of graphical statics, and with a study of elastic deflections and deformations. By this stage, 136 of the 823 pages have been covered.

The next section considers in some detail the solution of linear simultaneous equations using such devices as determinants and matrices. This concentration on simultaneous equations leads to a long chapter on the solution of statically indeterminate systems. The study of all the major methods of the solution of statically indeterminate structures covers more than 500 pages and forms the major part of this work. All methods from area-moments to moment distribution and iteration methods are covered not only for simple structures but also for structures containing curved and inclined members. Influence lines are well treated and simple space frames are dealt with. Throughout the chapters there are occasional summaries, and a division of the chapter into sections and sub-sections makes it easy to find the type of problem in which the reader is interested.

The rest of the book deals with more advanced work such as Vierendeel frames and such features as haunched beams are, of course, well covered. The book is well produced with many diagrams, and as a treatise is of high standard. It is, however, of limited application in this country where relatively few structural engineers can read technical German and for this reason it is unlikely that the book will appear in many design offices. This volume, in English, would be of much greater value.

W.F.C.

Statically Indeterminate Structures, by Jack R. Benjamin. (New York and London : McGraw-Hill Book Co. Inc., 1959). 9 in. × 6 in., 350 plus ix pp. 85s. 6d.

This text-book presupposes a knowledge of structural analysis—elastic and plastic—up to graduate level. It points the way to the most effective use of this knowledge in design procedures. The aim of the Author is to teach the young engineer designer how to make intelligent approximations and the intelligent use of the results and methods of structural analysis.

Emphasis is always on the shape of the deflected structure and the positioning of points of contraflexure leading in the end to a statical problem. These ideas are developed in the earlier chapters and explained by means of specific examples of continuous beams, rigid frames subjected to vertical loads and rigid frames subjected to lateral loads. The chapter dealing with the approximate analysis of shear-wall structures subjected to lateral loads is novel in that so many text-books on both civil and structural analysis and design have been sadly lacking in this respect. In the treatment here the emphasis is on the physical manner in which loads are disposed throughout the structure. The two concluding chapters on Structural Forms and Relation of Analysis to Design should be of considerable value to the young engineer meeting problems in practical design after the more academic approach to analysis. The various structural forms are reviewed and their merits compared. The last chapter on the relation of analysis to design rounds off what is undoubtedly a most stimulating book for the young engineer.

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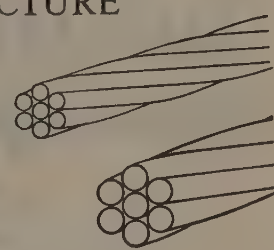

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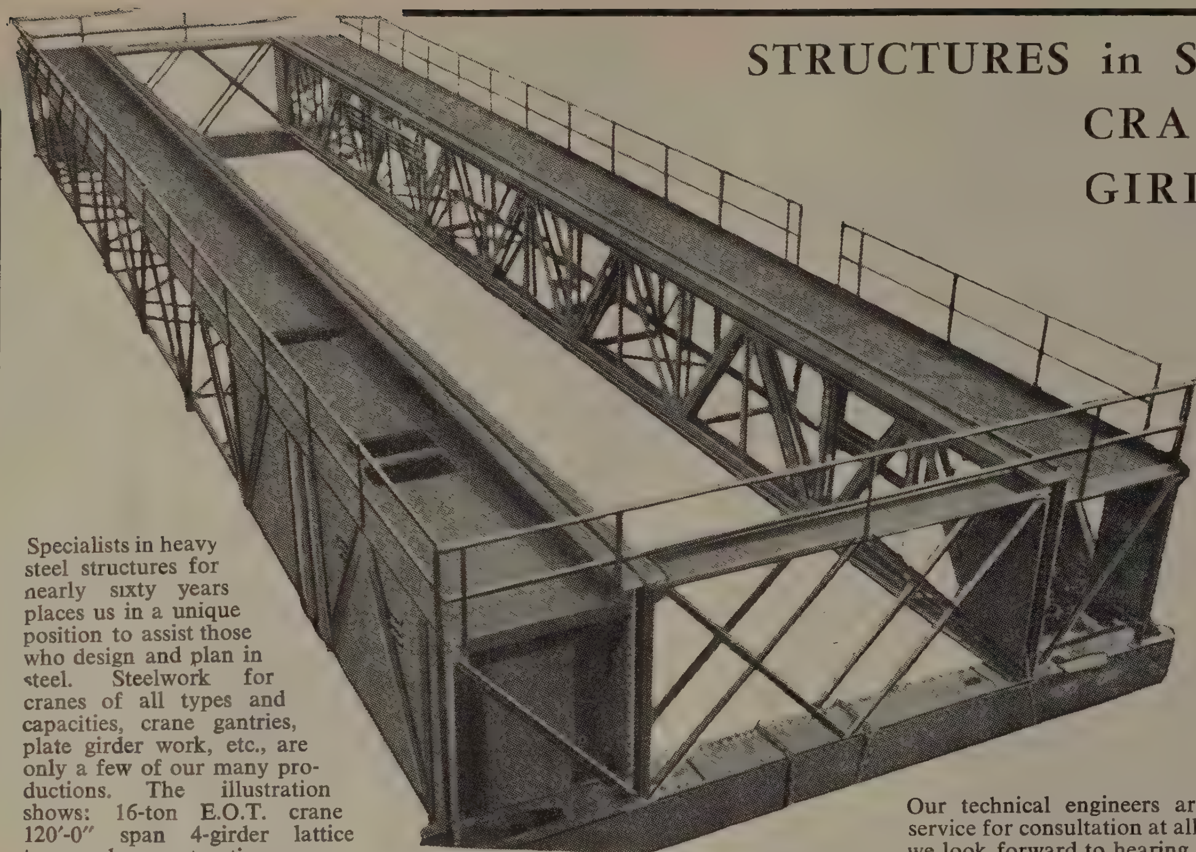

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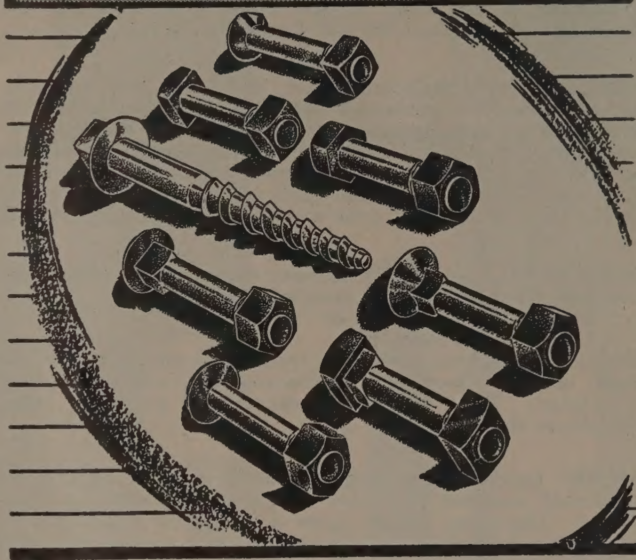

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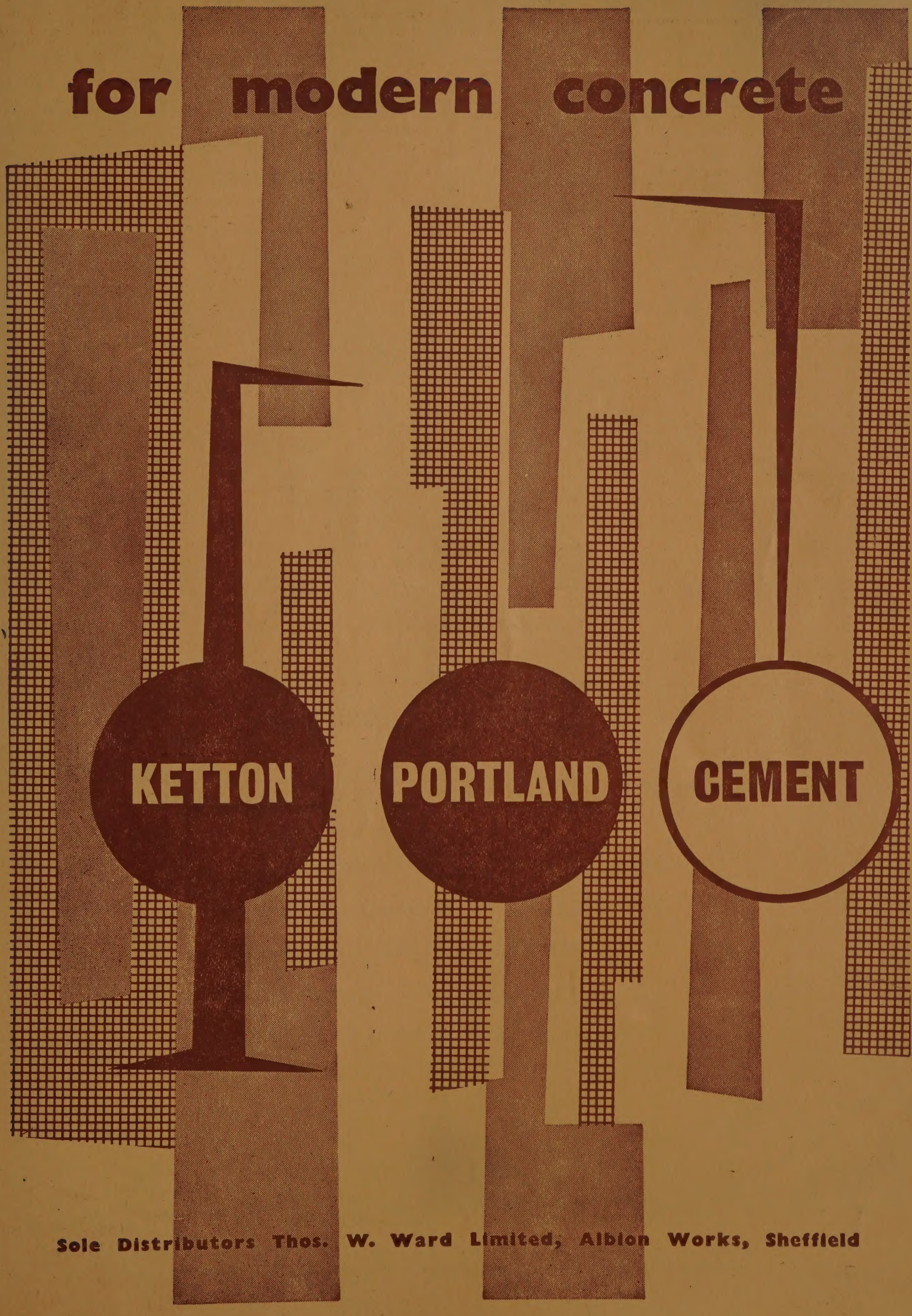
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